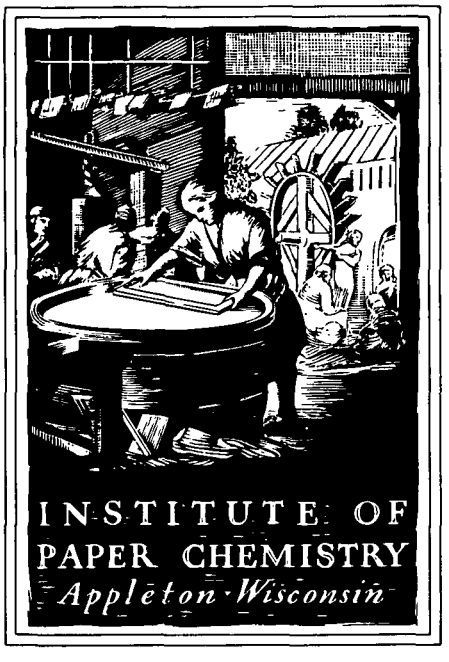
Feb. 10, 1984

PROJECT ADVISORY COMMITTEE

Subcommittee on

Engineering

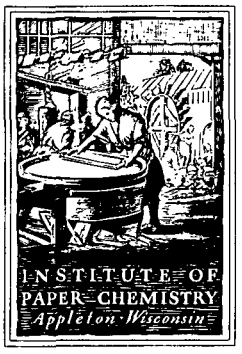


IPC STAFF STATUS REPORTS

This information represents a review of on-going research for use by the Project Advisory Subcommittees. The information is not intended to be a definitive progress report on any of the projects and should not be cited or referenced in any paper or correspondence external to your company.

Your advice and suggestions on any of the projects will be most welcome.

FOR MEMBER COMPANIES ONLY



THE INSTITUTE OF PAPER CHEMISTRY
Post Office Box 1039
Appleton, Wisconsin 54912
Phone: 414/734-9251
Telex: 469289

February 28, 1984

TO: Members of the Engineering Project Advisory Committee

Enclosed is advance reading material for the March 21-22 meeting of the Engineering Project Advisory Committee. Included are status reports for active projects, a tentative agenda, and a current membership list.

Please note that the Research Advisory Subcommittees have become Project Advisory Committees, in response to several issues raised late last fall, and the starting time of the meeting has been changed from 1:00pm to 10:00am. To confirm, the spring meeting of the Engineering Project Advisory Committee is scheduled to start at 10:00am on March 21 and end by 12:00 noon on March 22. The October 24-25, 1984 meeting will follow a similar time schedule.

Rooms have been reserved in the Continuing Education Center, and meals will be provided as stated on the agenda. Please call my secretary, Evonne Ludwig (414)738-3320, to indicate your attendance.

We look forward to meeting with you in March. Please let us know if we may help with your arrangements.

Sincerely,

Clyde

Clyde H. Sprague, Director
Engineering Division

CHS/el
Enclosures

TABLE OF CONTENTS

	Page
TABLE OF CONTENTS	i
AGENDA	ii
PROJECT ADVISORY COMMITTEE MEMBERSHIP LIST	iii
Project 3309: Fundamentals of Corrosion Control in Paper Mills	1
Project 3556: Fundamentals of Kraft Liquor Corrosivity	37
Project 3384: Refining of Chemical Pulps for Improved Properties	52
Project 3480: Wet Pressing Fundamentals	71
Project 3470: Fundamentals of Drying	82
Project 3479: Higher-Consistency Processing	104

* * * PRELIMINARY AGENDA * * *

ENGINEERING PROJECT ADVISORY COMMITTEE MEETING

March 21-22, 1984
The Institute of Paper Chemistry
Continuing Education Center (CEC)
Appleton, Wisconsin

* * * * * * * * * * *

Wednesday, March 21, 1984

10:00am	--	INTRODUCTION	Sprague/Kramer
		PROJECT REVIEWS	
10:15	--	Fundamentals of Corrosion Control in Paper Mills	Bowers
11:15	--	Fundamentals of Kraft Liquor Corrosivity	Yeske
12:15pm	--	LUNCH - CEC DINING ROOM	
1:15	--	Refining of Chemical Pulps for Improved Properties	Sinkey
2:15	--	Wet Pressing Fundamentals	Sprague
3:15	--	BREAK	
3:30	--	Fundamentals of Drying	Ahrens
4:30	--	Higher-Consistency Processing	Sinkey
5:30	--	COCKTAILS	
6:15	--	DINNER - CEC Dining Room	
7:15	--	Recent Developments in Paper Physics	Baum

Thursday, March 22, 1984

7:15am	--	BREAKFAST - CEC Dining Room	
8:00	--	Discussion of Projects	Committee & Research Staff
9:30	--	BREAK	
9:45	--	Continued Discussion of Projects	
10:30	--	Report Preparation	Committee
11:30	--	Adjourn	
	--	LUNCH - CEC Dining Room	

* * * * * * * * * * *

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

Status Report

to the

ENGINEERING PROJECT ADVISORY COMMITTEE

Project 3309

FUNDAMENTALS OF CORROSION CONTROL IN PAPER MILLS

February 10, 1984

PROJECT SUMMARY FORM

DATE: February 1, 1984

PROJECT NO. 3309 - Fundamentals of Corrosion Control in Paper Mills

PROJECT LEADER: D. F. Bowers

IPC GOAL:

Increase the useful life of equipment by proper selection of materials of construction and by identifying suitable process conditions.

OBJECTIVE:

To improve the life of paper machine suction rolls by corrosion and corrosion fatigue studies and laboratory investigations of failure preventative measures.

CURRENT FISCAL BUDGET: $130,000

SUMMARY OF RESULTS SINCE LAST REPORT: (October, 1983 - January, 1984)

Test specimens machined from five blocks of suction roll alloy shells were evaluated for corrosion resistance in three simulated white water environments. The surface finish of the specimens was similar to the condition on the inside surface of suction roll holes. All alloys, i.e., CA-15, CF-3M, A-75, A171, and 1N bronze, actively corroded at micro-defects on the surface. Requests for the other alloys, e.g., forged and rolled/welded rolls, continued; shipment expected late February and early March. The investigation of shot peening and hole burnishing to improve roll life has also continued; coupons of each alloy mentioned above are currently being shot peened and the hole burnishing technique is being demonstrated on sections from old roll shells. The literature review is still in progress; final report is expected prior to the meeting.

FUNDAMENTALS OF CORROSION CONTROL IN PAPER MILLS

INTRODUCTION

Suction rolls cost from $350,000 to $1,000,000. Depending on the roll alloy and application, running time or life may vary from two to twenty years. Simple arithmetic shows that net savings for each month of extended life for "low" cost, long life rolls is $1,500, and ten times that figure, or $15,000 per month, for the same roll with low (two yr.) life. Similar calculations for the more expensive roll indicate possible savings of $4,200 and $42,000 per month extension for low and long lifetimes, respectively. Additionally, the paper companies must pay for insurance premiums, expensive analyses of roll failures and, most importantly, for production losses during inspections or replacement of failed rolls. Obviously, significant benefits will accrue if roll life can be extended.

The complexity of the task of improving life stems from the imposed design methods of manufacture for a given metallurgy, and the combined action of corrosion fatigue during operation. However, there are several logical elements which this project must address. First, we must select the proper alloy for the stress/environment condition in which the roll will operate. This requires knowledge of "what is known" about different alloy types and their performance in rolls on various machines. A literature review, in progress, is aimed at this assessment. From the standpoint of corrosion resistance, comparisons of alloy fatigue resistance and performance in white water are needed. A joint effort by Beloit and Sandusky, involving exposure of test spools containing

various alloys (stressed and unstressed) in various locations on different paper machines, in currently underway. Each is also separately engaged in laboratory tests on alloys. The Industrial Materials Research Institute of Canada has recently published results of corrosion fatigue studies of Kubota alloy 171. This effort may be continued for other alloys; follow-up is in progress. TAPPI, via its suction roll subcommittee, is active in developing "agreed upon" methods to evaluate roll design and corrosion fatigue strength. CPPA recently published a survey of suction roll performance in Canada. The Swedish Corrosion Institute recently expressed interest in the pursuit of suction roll alloy evaluations. In addition, there is a large volume of literature on the general subject of metals, which is relevant to understanding the limitations of roll alloys. Thus, there will be much to draw from the forthcoming project report with regard to proper alloy selection and the direction of future project work.

A second step to roll life improvements, agreed upon in the last PAC meeting, is to distinguish between current methods of roll manufacture, e.g., castings vs. forgings vs. rolled and welded methods, for possible advantages in corrosion/corrosion fatigue resistance. At least eleven alloys must be evaluated for this study. The following report describes results from corrosion tests on the five cast alloys currently available. Since an important aspect of metal corrosion resistance is surface condition, the five alloys were machined and tested with a surface finish (root mean square, surface profile, peak to valley, or RMS) corresponding to the reported value for the inside surface of the hole in a suction roll. Corrosion, severe in some cases, occurred on all five alloys at surface active sites, regardless of environment. This represents somewhat of a dilemma because the surface active sites may include casting

defects and artifacts from the machining process. Further discussion of this dilemma and the test results are provided in the following report.

The third step of our plan for this year is a preliminary assessment of two known corrosion fatigue deterrents, shot peening and corrosion inhibitors. In response to discussions at the October meeting, emphasis on inhibitors has been reduced because of high procurement costs and low recovery in roll applications, and the fact that most rolls, particularly those made from stainless steel, fail due to stress fatigue, not corrosion. Further investigation will include cost analysis and feasibility for improvement, based on current and subsequent testing. The interaction with Metal Improvement Company (MIC) to define costs and effectiveness of shot peening is continuing. Peening of the entire length of the inside surfaces of roll shell holes was successfully accomplished. However, the resulting surface was rough enough to require polishing. Currently, the feasibility of automatically burnishing the holes in a roll shell is being studied; as an alternative to peening, burnishing single holes in an old, previously failed suction roll section was successful. Coupons of each of the five available alloys were sent to MIC for peening. Upon return, the peened coupons will be evaluated for corrosion resistance. Further details of this investigation will be presented at the March, 1984 meeting.

There are other steps which require more long range study in the improvement of roll life, and these will be the subject of future project research. Because of the roll failure mode, these necessarily require studies of improved metal surfaces, which discourage crack initiation, as well as methods to retard crack growth. A forecast of these plans is described under Future Work in the final section of this report.

SELECTION OF ALLOYS FOR EVALUATION

Table I gives the initial list of alloys selected for this study. Several other alloys are used in suction rolls and some have been requested, so additions or modifications of this list are likely. Among the four groups, the bronze and austenitic alloys are primarily used for couch and suction pick-up rolls, while the higher strength martensitic and duplex alloys are used for press rolls. Note that forged and rolled/welded alloys are indicated along with the more conventional centrifugally cast alloys in Table I. Nickel aluminum bronze is a continuously cast alloy.

Sample pieces from five cast rolls (#1, #3, #6, #8, and #9, Table I) have been received and machined into test specimens. The appearance of these cast blocks is shown in Fig. 1. Metal properties and specimen types were described previously. Receipt of samples from the other cast alloys is expected shortly while the test pieces from forged or rolled/welded shells are expected about mid-March.

In planning the initial phase of this work, it was decided to test the alloys by using specimens with a surface finish similar to that of a suction hole inside surface. Selection of finish was based on information from the supplier. The drilling/reaming technique, i.e., twist and gun drill, produces the hole surface finish, but this technique varies with alloy and/or supplier. Thus, for the alloys currently under study, the bronze, A-75 and KCR171 specimens were machined to a 40-50 RMS finish, while specimens of CA-15 and CF-3M were furnished with a surface finish of 250 RMS. A surface comparator, shown in Fig. 2, was used to check the finish prior to corrosion testing.

TABLE I

Suction Roll Alloys - Typical Composition (Wt.%)

Bronze Alloys

(1) 1N - 85% Cu.; 5% ea. Sn., Pb., Zn.

2) Nickel Aluminum - 84% Cu.; 9% Al.; 3% Fe.; 4% Ni.

Austenitic Alloys

(3) CF-3M (similar to AISI316L) - 18% Cr.; 12% Ni.; 2% Mo.; Bal. Fe

(4) PM-3-1809N - same as CF-3M above, only forged.

(5) Alloy 63 (similar to AISI316) - 22% Cr.; 9% Ni.; 2.75% Mo.; Bal. Fe. (contains some ferrite)

Martensitic Alloys

(6) CA-15 (similar to AISI410) - 13% Cr.; 1/2% Mo.; Bal. Fe.

(7) PM-4-1300 - same as CA-15, only forged.

Duplex Alloys

(8) A-75 - 26% Cr.; 6% Ni.; Bal. Fe.

(9) KCR-A-171 - similar to A75, only 1.0% Mo. added.

(10) PM-2-2309 - similar to A171, but forged.

(11) 3RE60 - 18% Cr.; 5% Ni.; 3% Mo.; Bal. Fe. (rolled and welded alloy)

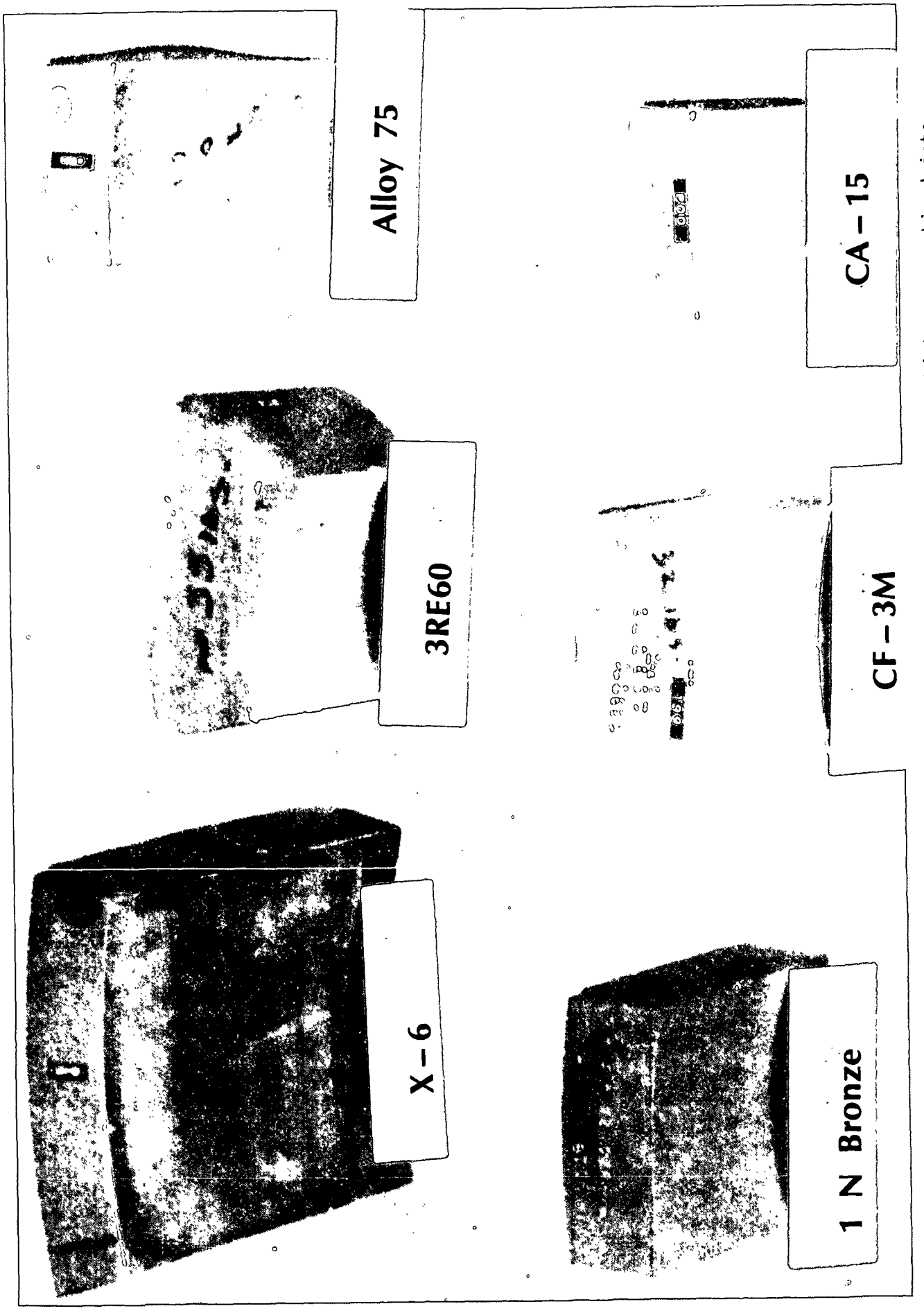


Figure 1. Photograph of test blocks from five cast, suction roll shells which were machined into corrosion test specimens. (Enlarged 2X.)

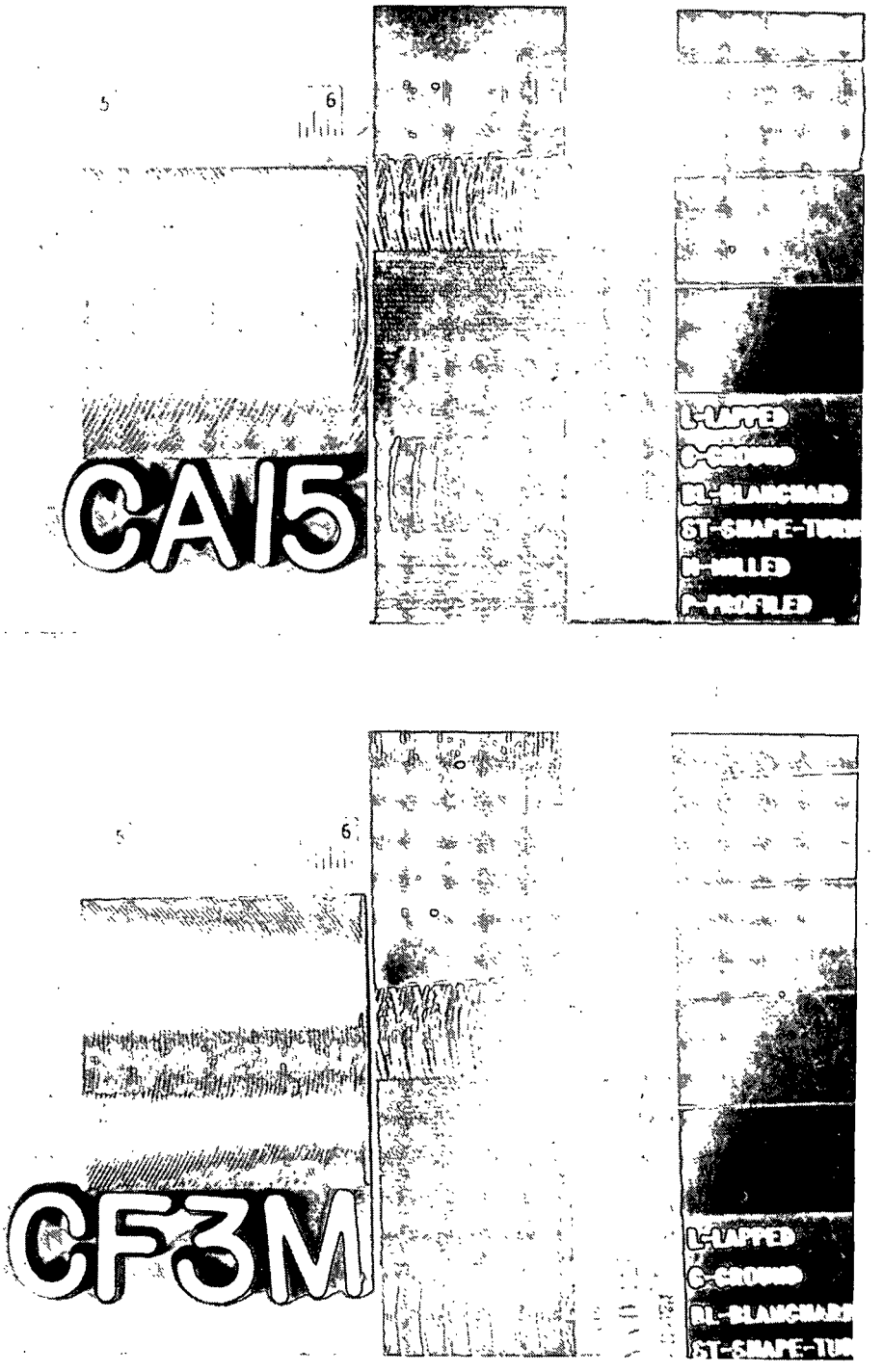


Figure 2. Photograph of surface finish comparator and test specimen inspection.

CORROSION TESTS

Exposure (weight loss) tests were conducted on 1¼ inch square coupons. Duplicate coupons of each alloy were exposed in static and recirculating water systems. Corrosion potential measurements were continuously monitored in the static tests (Fig. 3) and this data processed automatically, via., Apple II/TecMar, computer acquisition. Periodic potential measurements were taken on coupons exposed to flowing (20 gpm pump) water (Fig. 4). Both systems were sealed to be air tight, but the water was not deaerated. All tests were conducted at 55°C.

Anodic polarization scans were conducted on cylindrical specimens of each alloy except bronze; linear polarization tests were performed on bronze. The specimens were tested, as received, i.e., with surface (RMS) finish simulating the i.d. surface condition of the suction hole for that alloy.

Initial tests used a simulated white water which was formulated from TAPPI suction roll subcommittee information. Table II shows the composition and make-up of two water solutions (TAPPI I & II) which are intended for use as test media in TAPPI approved methods for corrosion fatigue testing of suction roll alloys (method currently under study). The more aggressive TAPPI II water was selected for the initial tests. All alloys except KCR171 were tested; the Alloy 171 test block was not received in time.

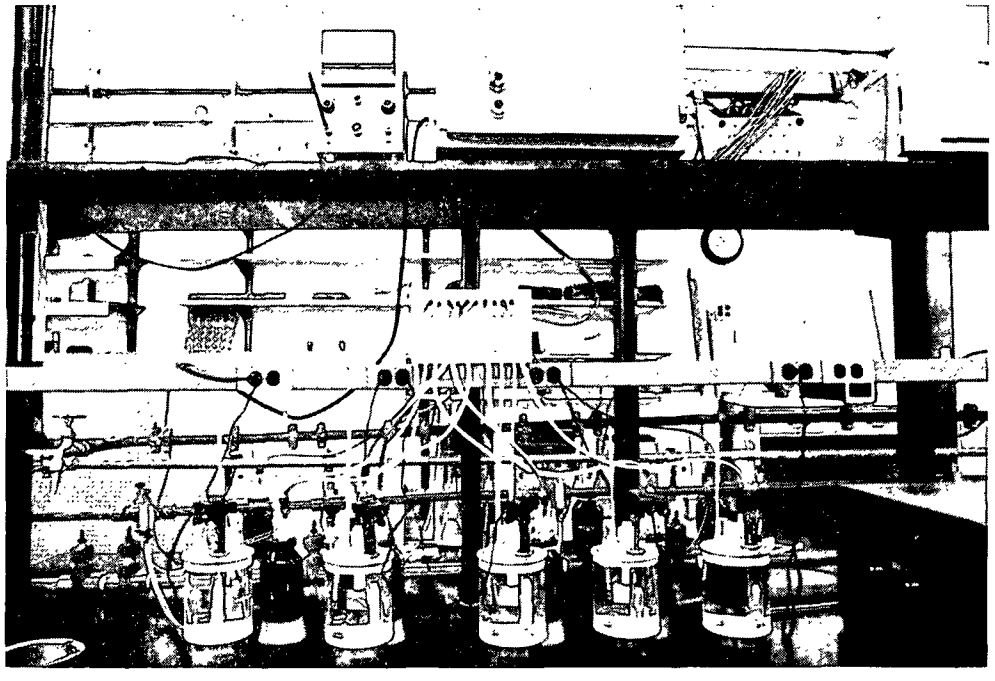


Figure 3. Static corrosion test system for coupon exposure in ten corrosion cells. Top - electrometer and timer. Bottom - test cells.

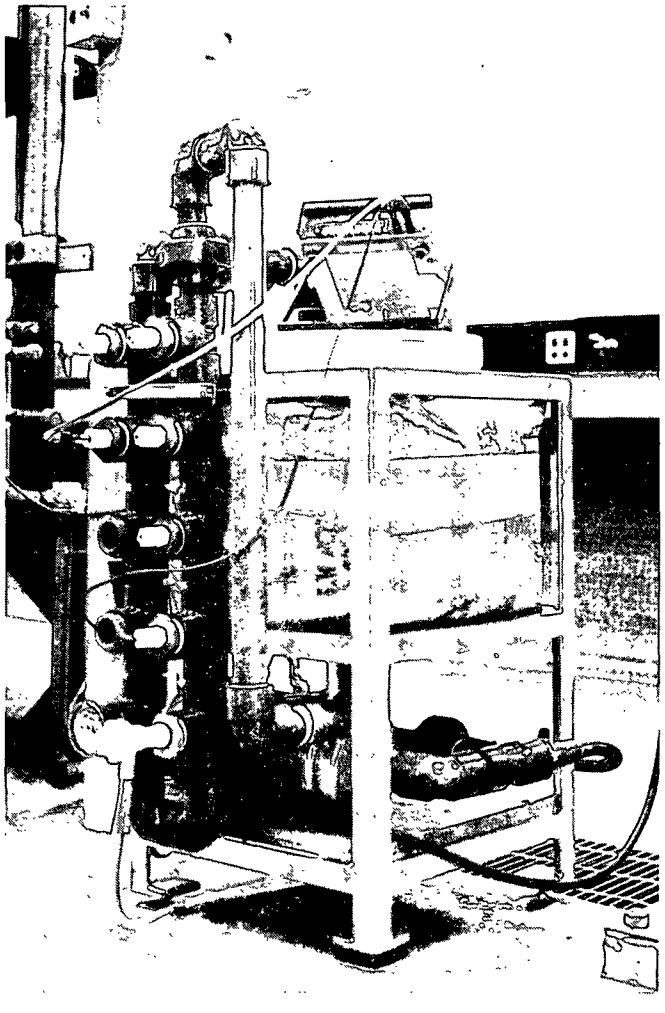


Figure 4.

Test system for evaluating corrosion of coupons exposed to flowing white water. Eight pipe tees provide access for coupons and reference electrode.

TABLE II

Simulated Paper Machine White Water Make-up & Composition

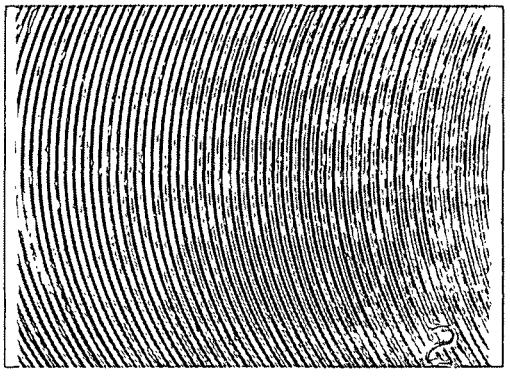
Type	pH	Sulfate (ppm)	Chloride (ppm)	Additives - Method
TAPPI I	3.5	1000	100	Sulfate added as reagent grade aluminum sulfate Chloride added as reagent grade sodium chloride
TAPPI II	3.5	1000	1000	Sulfate added as reagent grade aluminum sulfate Chloride added as reagent grade sodium chloride
IPC Check Analysis	3.5	1080	1010	
WWI*	4.1	500	200	Sulfate added as reagent grade sodium sulfate Chloride added as reagent grade sodium chloride
IPC Check Analysis	4.1	502	181	

* 50 ppm thiosulfate was added as sodium thiosulfate after above solution make-up and pH adjustment to 4.2

Severe localized corrosion was observed in all test systems regardless of alloy. Based on the appearance of the corrosion products, the attack appeared accentuated at defect sites on the surface. Figures 5 and 6 depict the surface defects for CF-3M and A75, respectively, which are respresentative of as received surfaces for all alloys. Note that the defect size is smaller for smooth surfaces, e.g., A75 (50 RMS) Fig. 6 compared to CF-3M (250 RMS) Fig. 7. In fact, other samples of these alloys, described under metallography later, were defect- free when polished to scratch-free surfaces.

Figures 7 and 8 show the extent of corrosion on coupons exposed in the static system to TAPPI II water. Rust was observed in the corroded defect sites on the iron based metals, e.g., CF-3M and A75 (Fig. 7). One major difference in coupon appearance between the static and flowing test systems was the predominance of crevice corrosion on coupons in the static system, e.g., see CA-15 (Fig. 8) and its absence in the flow system. Another difference was the elongation of localized attack in the direction of flow on coupons exposed in the recirculating water system (Fig. 9).

Anodic polarization scans at 0.6 v/hr. were made on CA-15, A75 and CF-3M in TAPPI II water, unaerated and deaerated with nitrogen. Active corrosion in the form of pitting at defect sites occurred at potentials 50 to 80 mv. more noble than the corrosion potential. Figure 10 shows the rapid activation kinetics for all alloys; note the instability in the current response, i.e., scribble in plot, soon after scanning above the open circuit potential which is indicative of pitting. The photographs in Fig. 11 show the appearance of A75 after polarization testing, which was typical for all alloys.



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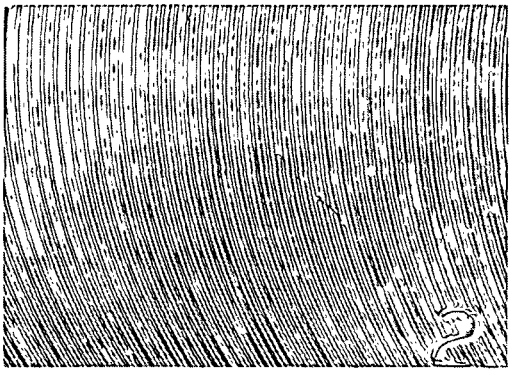

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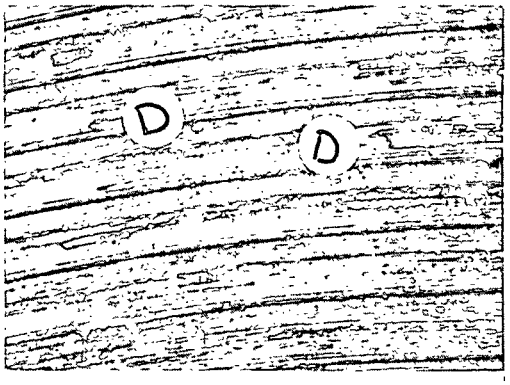

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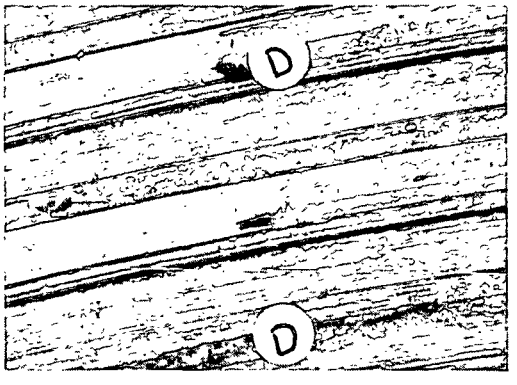

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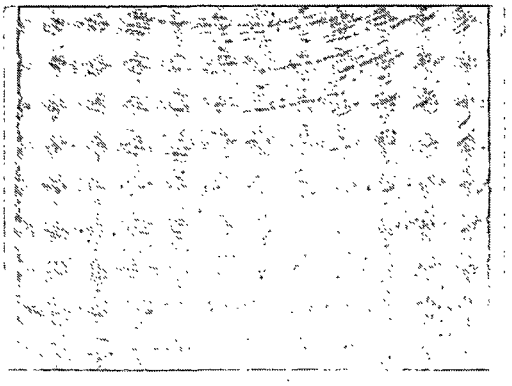
Figure 5. Characterization of specimen surface for CF-3M (250 RMS), as machined prior to test. Note surface defects marked "D".



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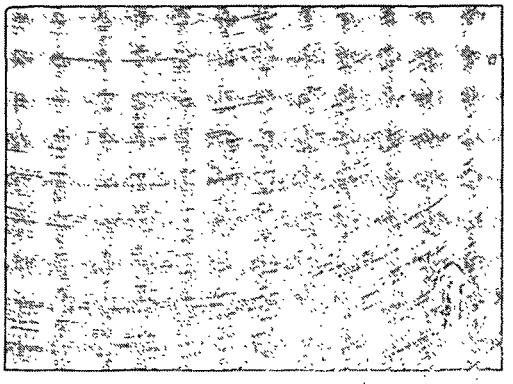

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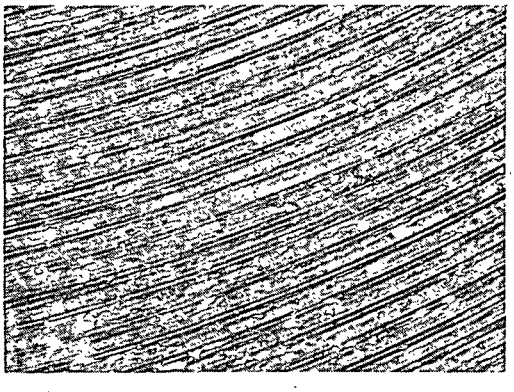

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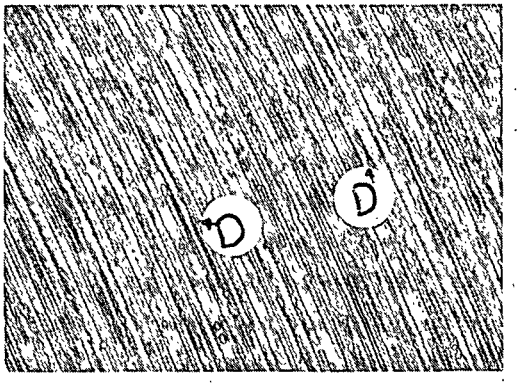

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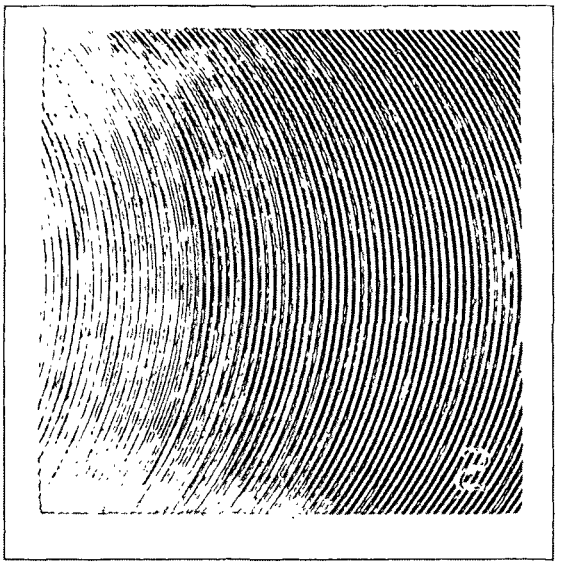
Figure 6. Surface characterization of specimens, A75 (50 RMS), as machined prior to test. Note defects at "D".



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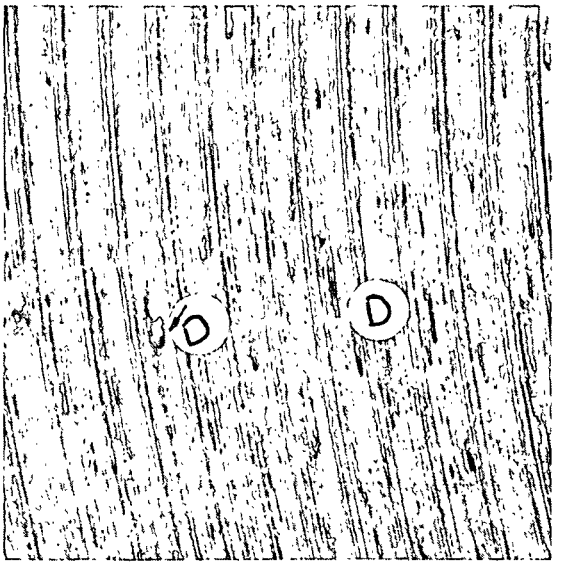
CF-3M



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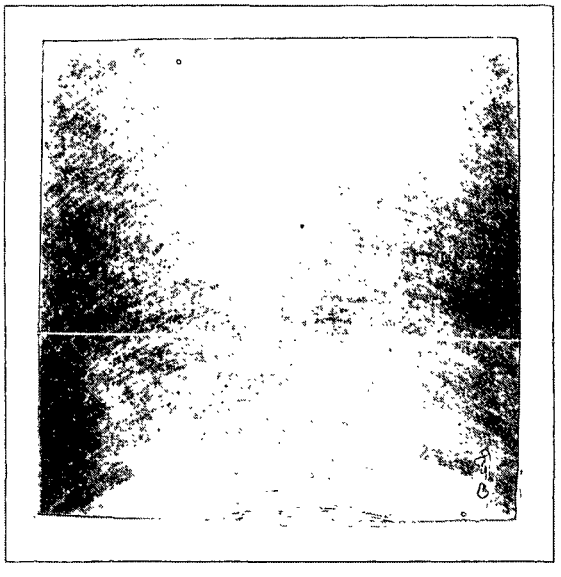

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A-75

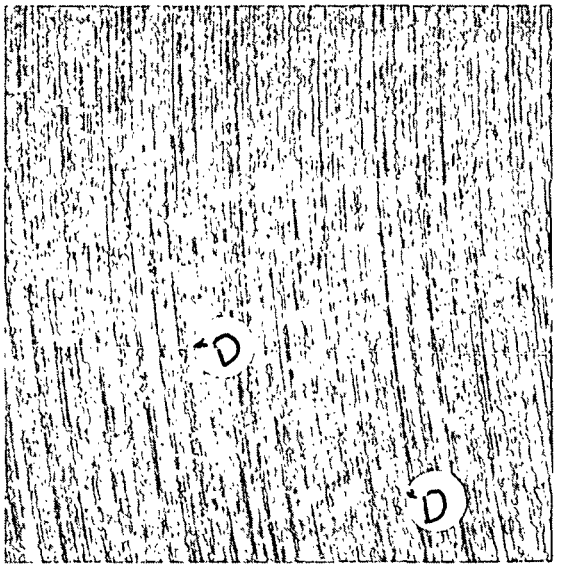

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Figure 7. Appearance of CF-3M and A75 after test in the static system - TAPPI II water. Corrosion (rust) was observed at sites marked "D".

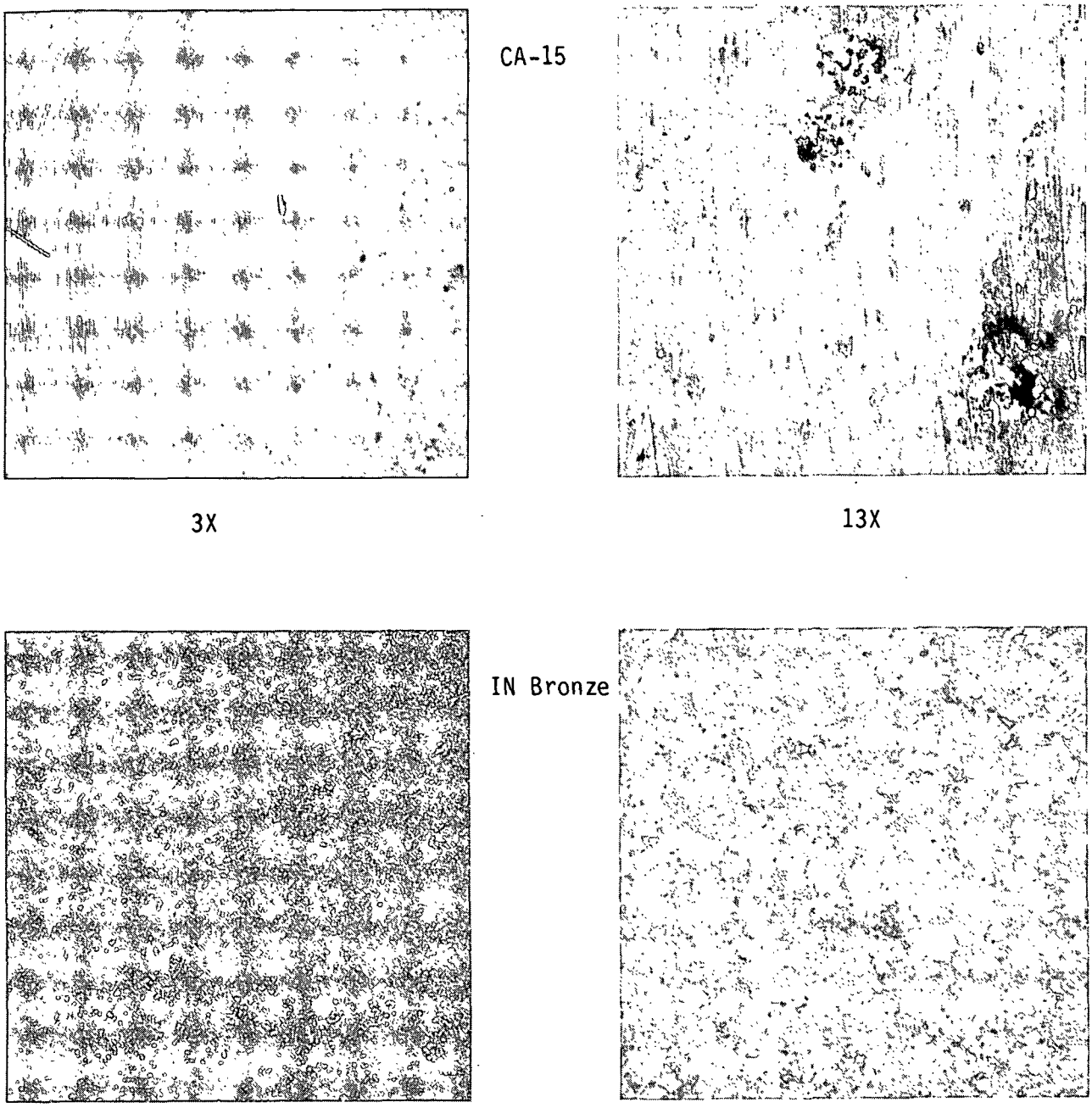


Figure 8. Appearance of CA-15 and bronze coupons after exposure (static system) to TAPPI II water. Note crevice corrosion on CA-15 coupon on top.

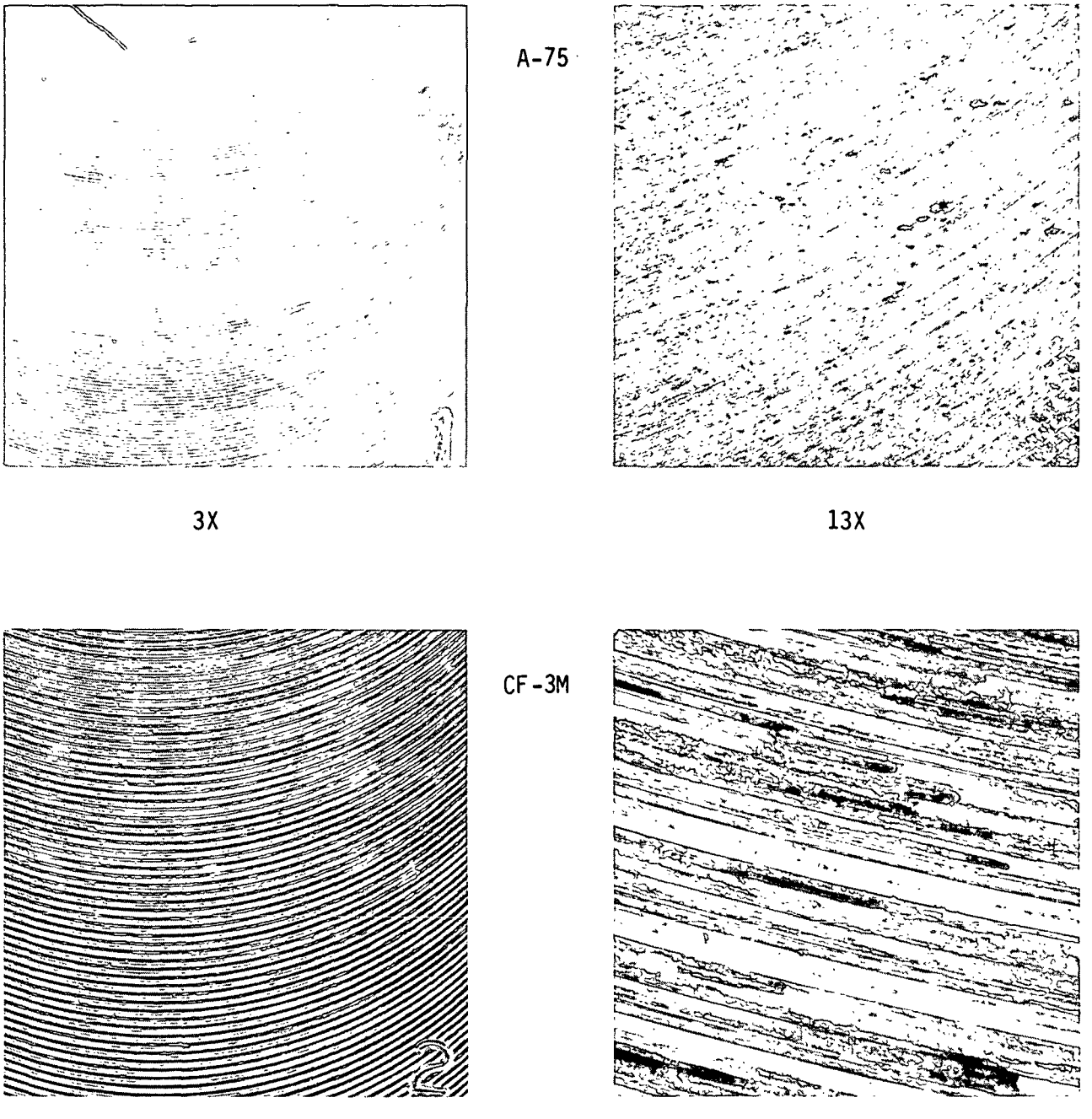


Figure 9. Appearance of A75 and CF3M coupons after exposure to flowing TAPPI II water. Note elongation and widening of former defect sites by corrosion.

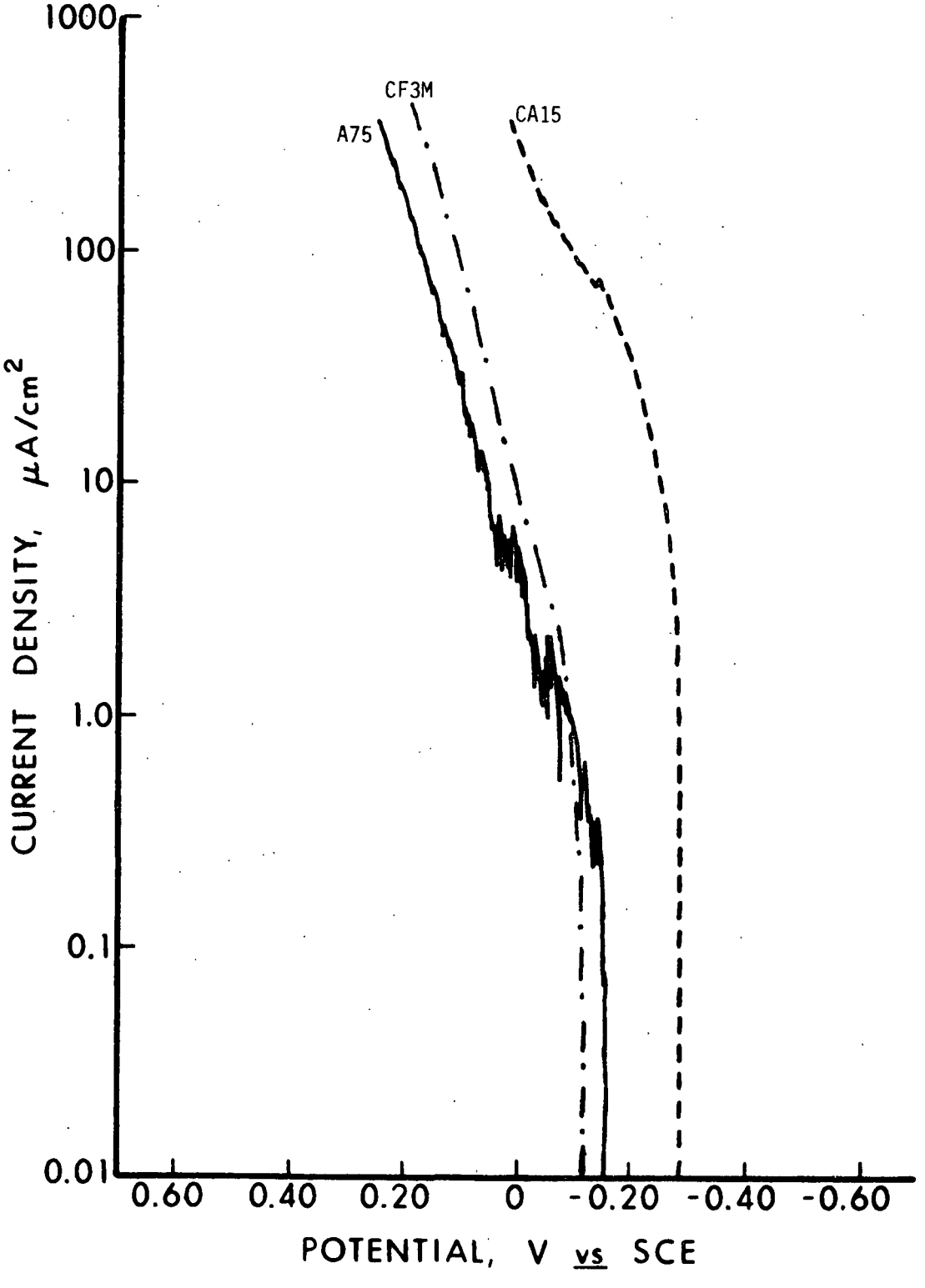
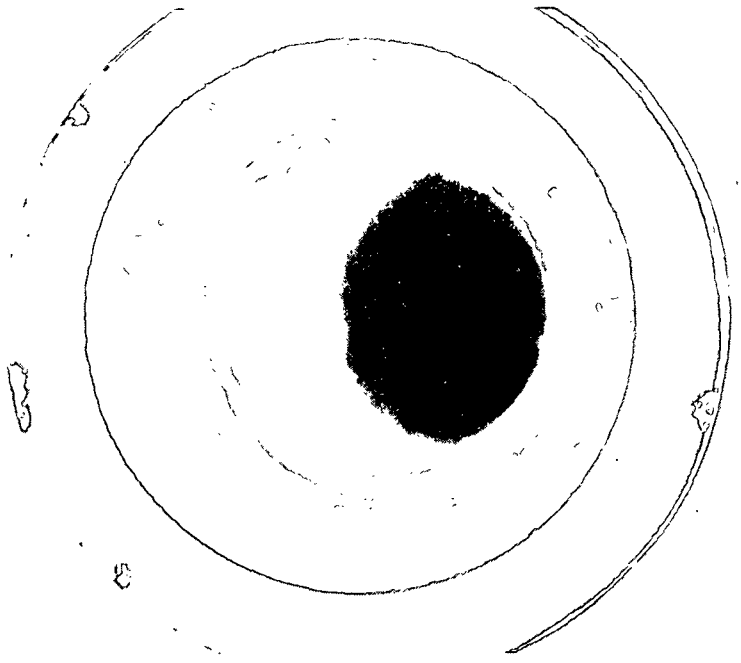
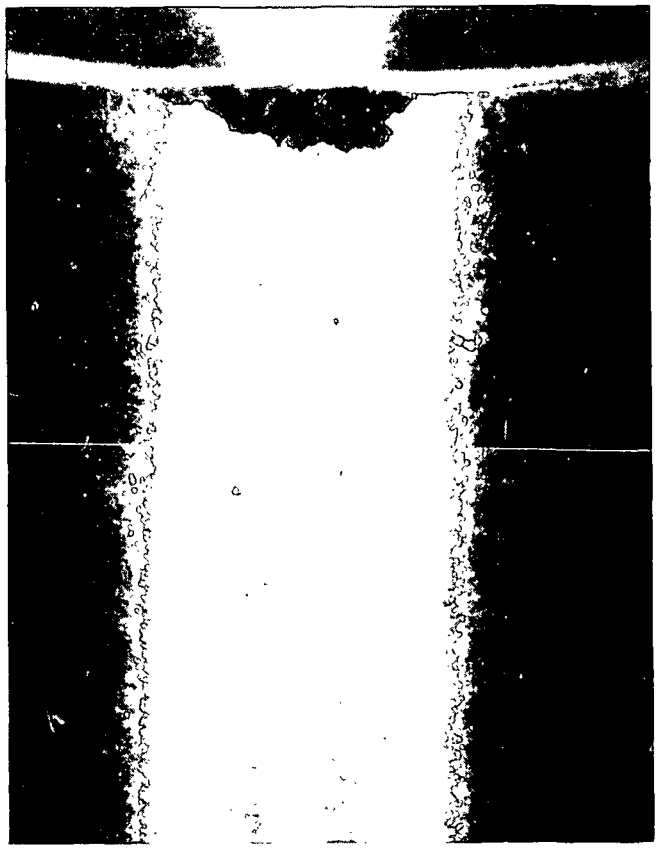


Figure 10. Anodic polarization behavior of suction roll alloys in TAPPI II water, 55°C, 0.6 v/hr.



13X



27X

Figure 11. Appearance of A-75 after anodic polarization in TAPPI II water, deaerated, 55°C, 0.6 v/hr.

Since the TAPPI II water failed to provide any meaningful differences among alloys, and its composition seemed unrealistic to wet end chemistry, several unsuccessful modifications to this formulation were attempted. The most successful recipe, depicted as WWI in Table II, consisted of sulfate, chloride and thiosulfate constituents dissolved in water of, ca., 4pH. While corrosion again occurred at defect sites, there was a preponderance of new pits, discernible differences between alloys, and good reproducibility of results for each alloy.

Figure 12 shows the potential decay behavior of each alloy during 150 hour exposure in WWI water at 55°C in the static system. Both bronze and CF-3M demonstrate preferred behavior as the potential rises with time in the noble direction. The jagged plot and active direction of potential for the other alloys indicate pitting attack. Duplicate specimens of each alloy were exposed for reproducibility evaluation. Figures 13-15 show the typically good agreement obtained between duplicates of each alloy. A comparison of alloys in the same family also demonstrated good agreement, as shown in Figures 16 and 17. The more distinct appearance of localized attack, which was achieved in these tests, is shown in Figs. 18 and 19.

Corrosion rate measurements were obtained by weight loss of each alloy in both static and flowing water. In addition, electrochemical corrosion rate determinations were performed on all alloys; CA-15 and bronze data are considered the most reliable. Table III lists this corrosion data. The bronze alloy was not included in the flowing system tests in order to avoid contamination from copper ions in the recirculating water. Coupon appearance of the stainless steel alloys after exposure to the flowing white water is shown in Fig. 20.

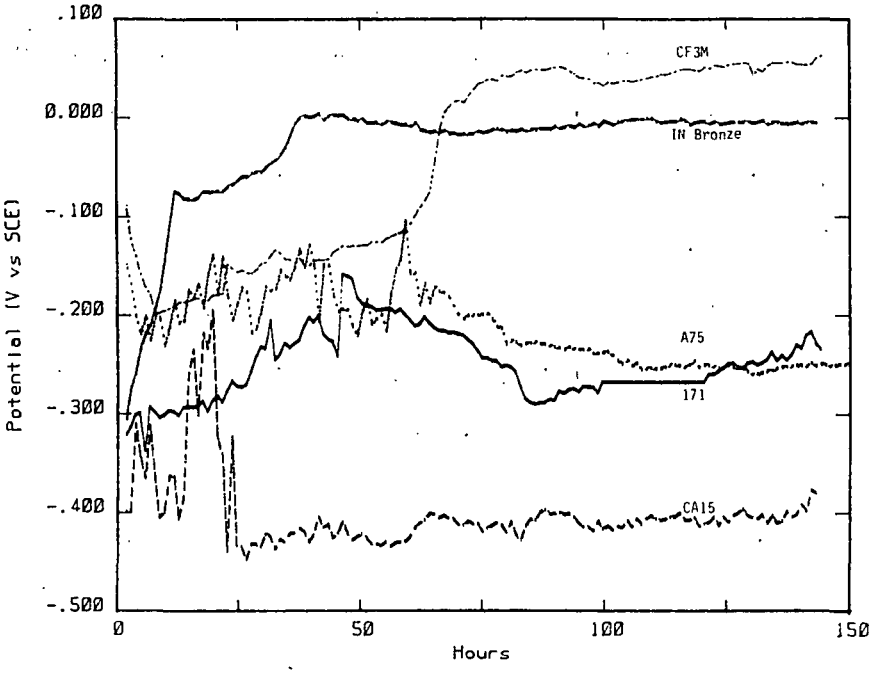


Figure 12. Potential decay behavior of suction roll alloys in WWI water, 55°C.

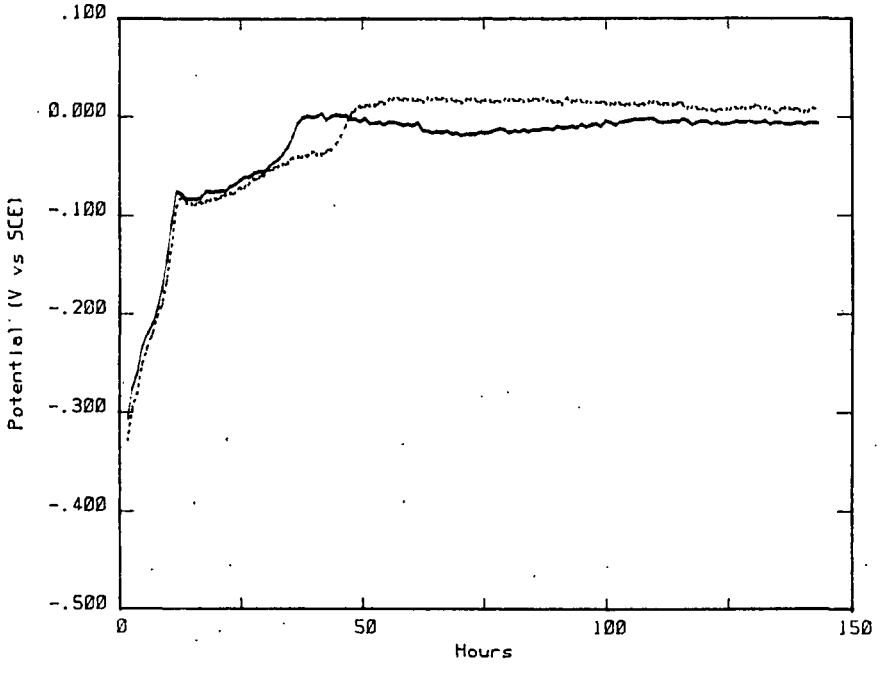


Figure 13. Comparison of potential decay behavior for duplicate specimens of 1N bronze in WWI water, 55°C.

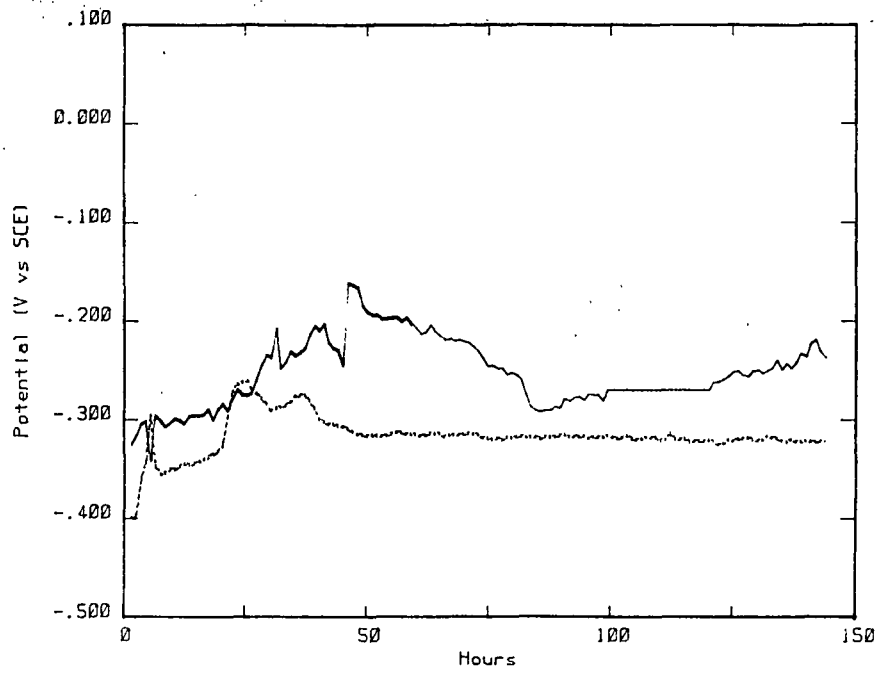


Figure 14. Comparison of potential decay behavior for duplicate specimens of A75 in WWI water, 55°C.

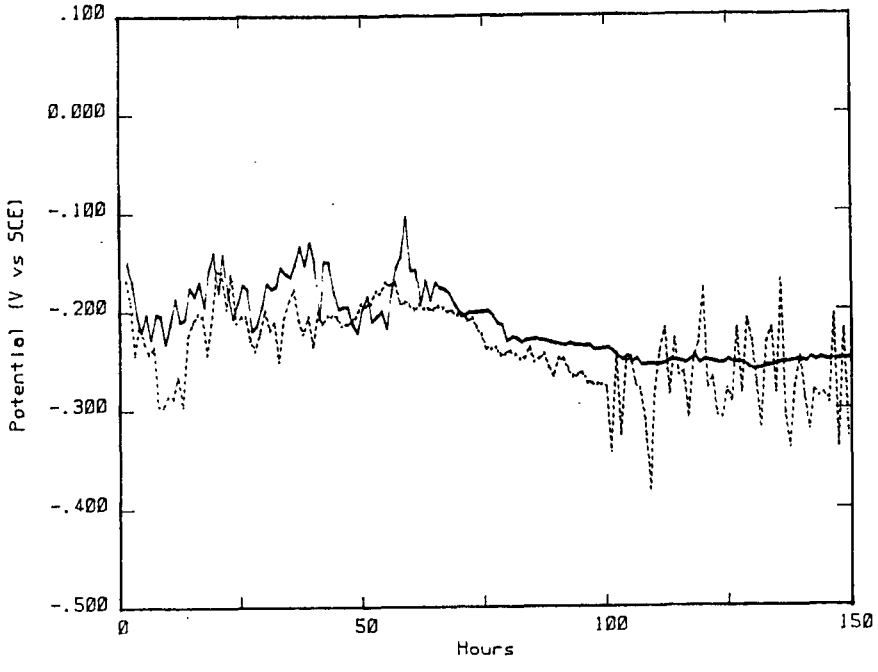


Figure 15. Comparison of potential decay behavior for duplicate specimens of KCR171 in WWI water, 55°C.

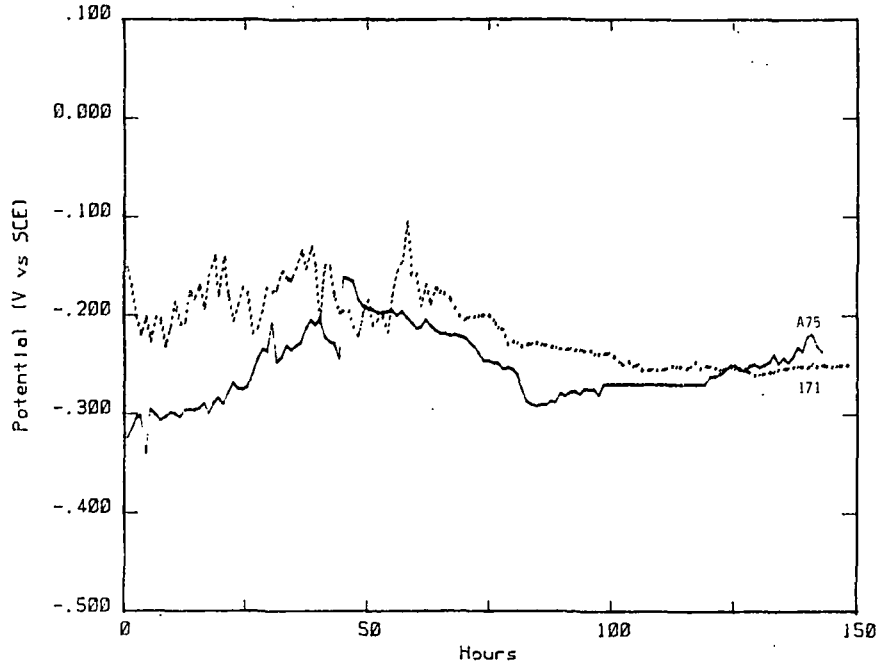


Figure 16. Comparison of potential decay behavior for duplex alloys, A75 and KCR171 in WWI water at 55°C.

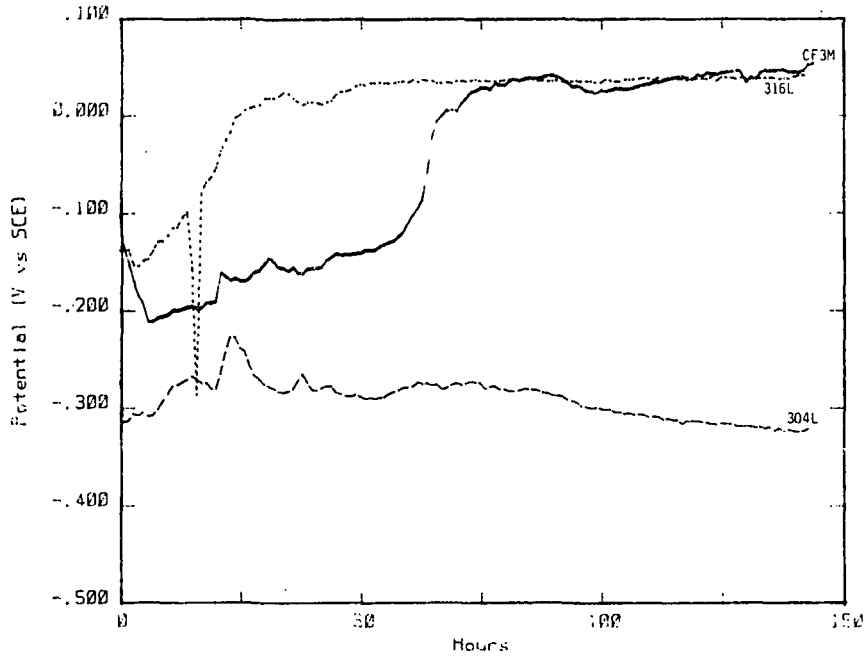


Figure 17. Comparison of potential decay behavior for austenitic alloys, CF-3M, AISI316L and 304L in WWI water at 55°C.

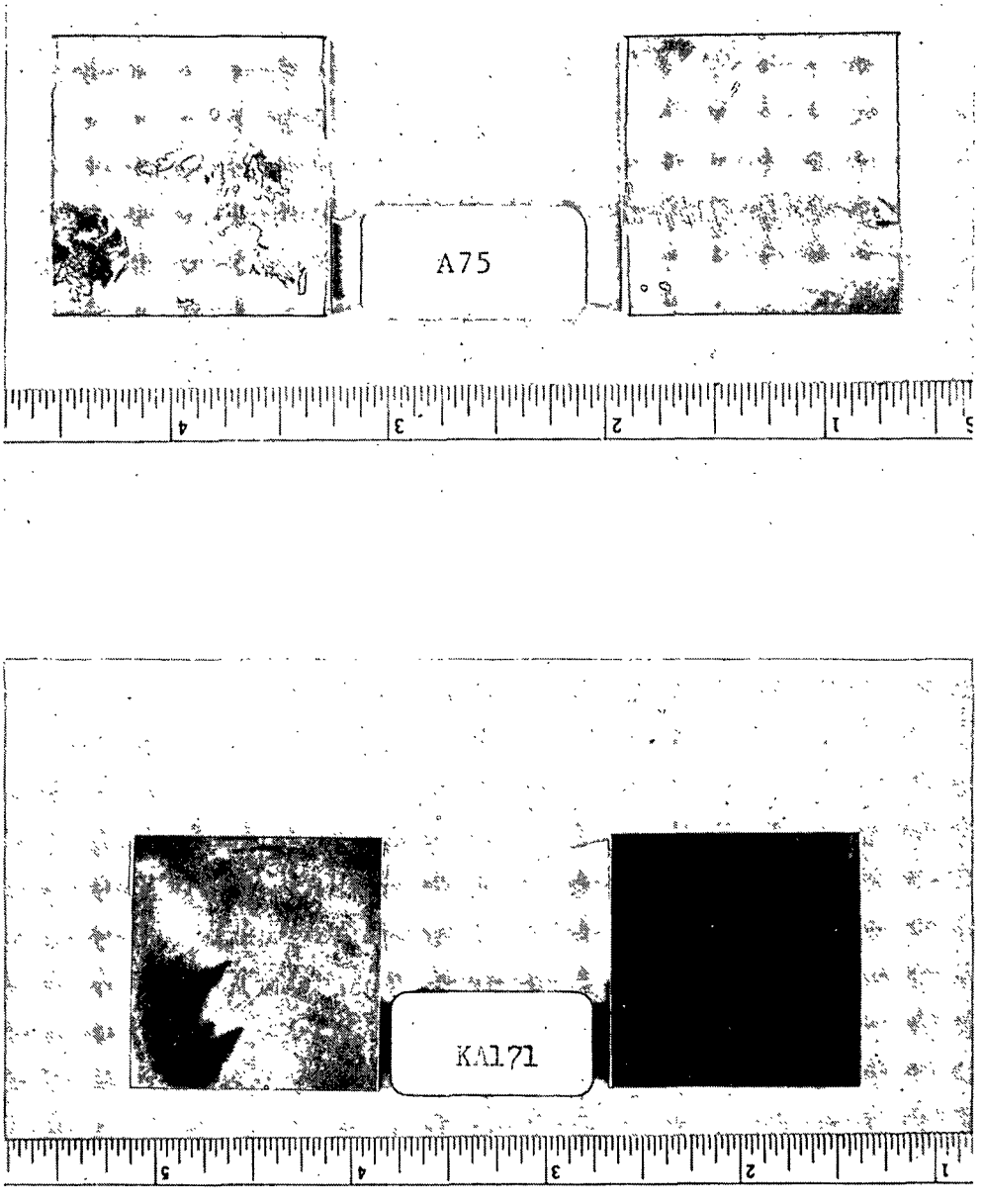
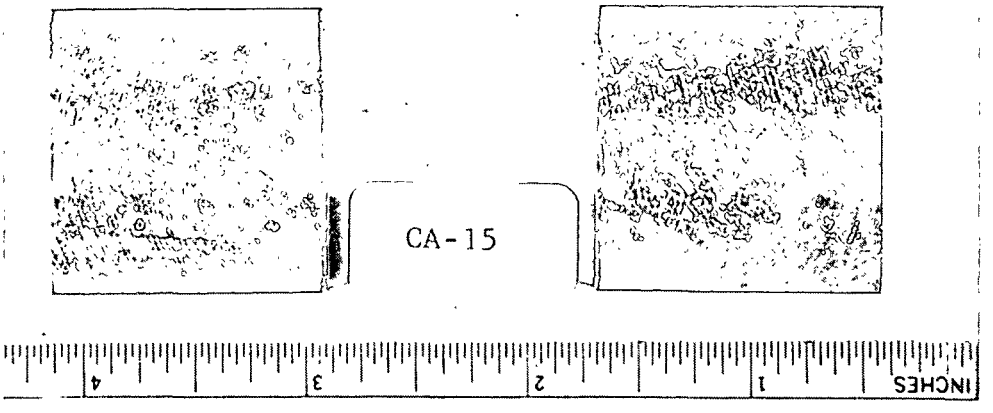


Figure 18. Appearance of duplex alloys after potential decay corrosion tests in WWI for 150 hours at 55°C.



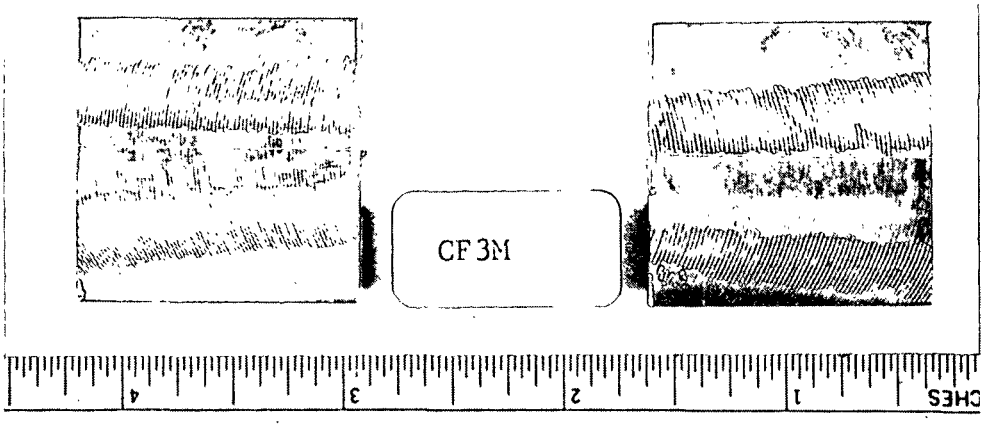


Figure 19. Appearance of suction roll alloy coupons, CF-3M and CA15 after potential decay test in WWI water for 150 hours at 55°C.

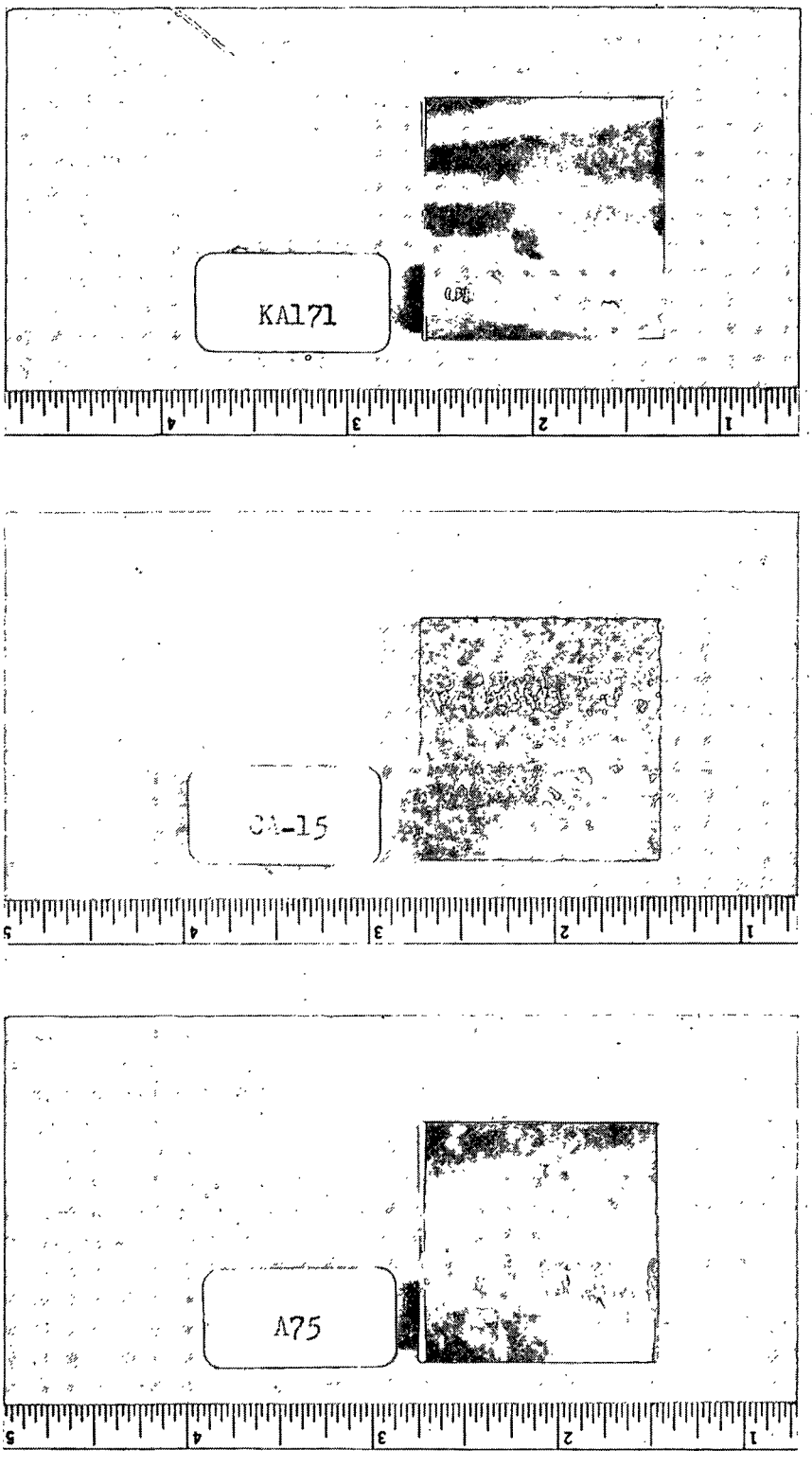


Figure 20. Appearance of suction roll alloy coupons after 150 hour exposure to 55°C flowing WWI water.

TABLE III

Corrosion Rate (Wt. Loss) of Suction Roll Alloys in Simulated White Water, 150 hours, 55°C.

Alloy Type	Corrosion Rate (MPY)		
	Static*	Flowing	Electrochemical
1N Bronze	18.0	- -	6.1
CA15	16.2	18.2	36.3
CF-3M	0.1	0.1	0.1
A75	2.4	0.7	1.1
K171	1.3	1.1	0.05

* Average from two specimens.

Anodic polarization test results for the stainless steel alloys are shown in Fig. 21. Again, rapid activation of corrosion and pitting is observed at applied potentials only slightly more noble than the rest potential. The most severe pitting occurred on test specimens of CA-15 (Fig. 22). The corrosion on CF3M, A75, and A171 was primarily in the regions of defects; though many new pits in "non-defect" areas were apparent. The plot of polarization results from tests on wrought AISI 316L is included in Fig. 21 to illustrate the difference in behavior between wrought and cast (CF-3M) alloys and to illustrate that passivity can be maintained on "defect-free" metal exposed to the WWI environment.

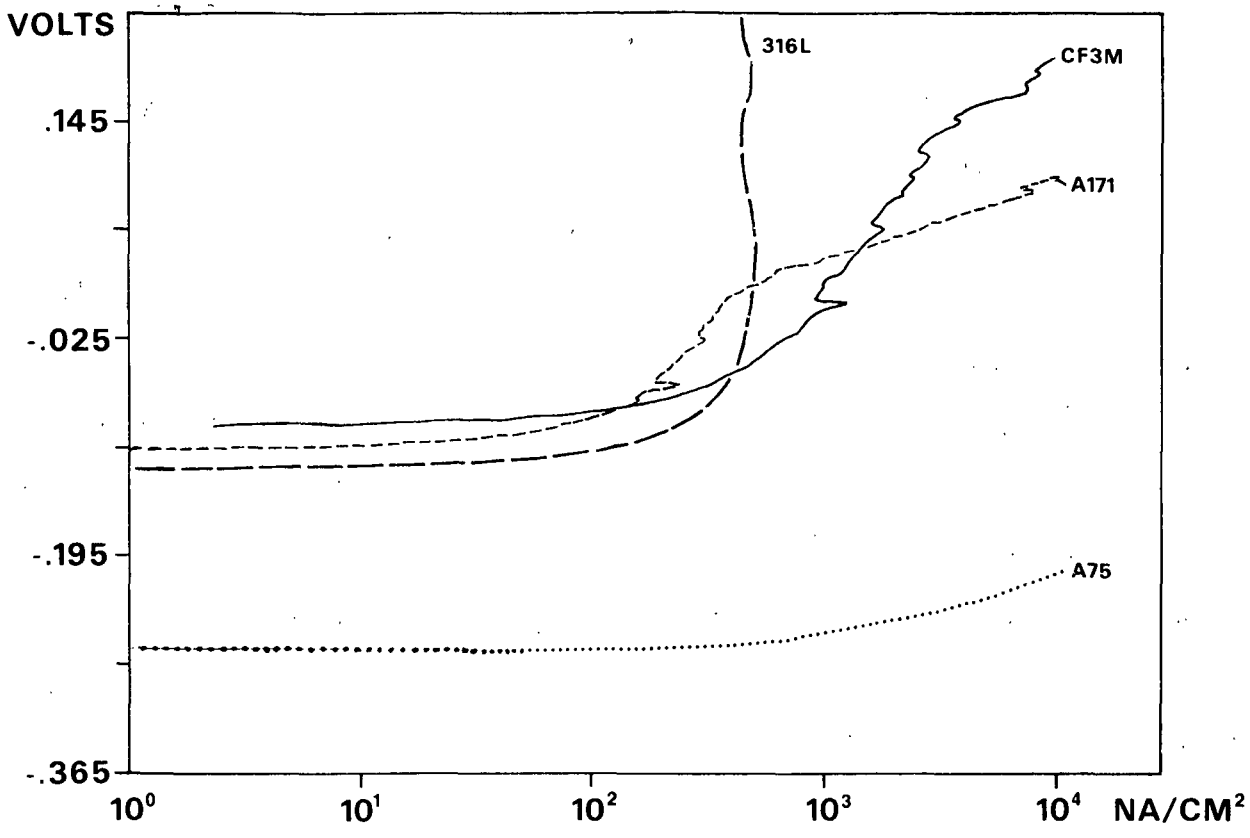


Figure 21. Anodic polarization behavior of suction roll alloys in WWI water, 0.3 v/hr., 55°C.

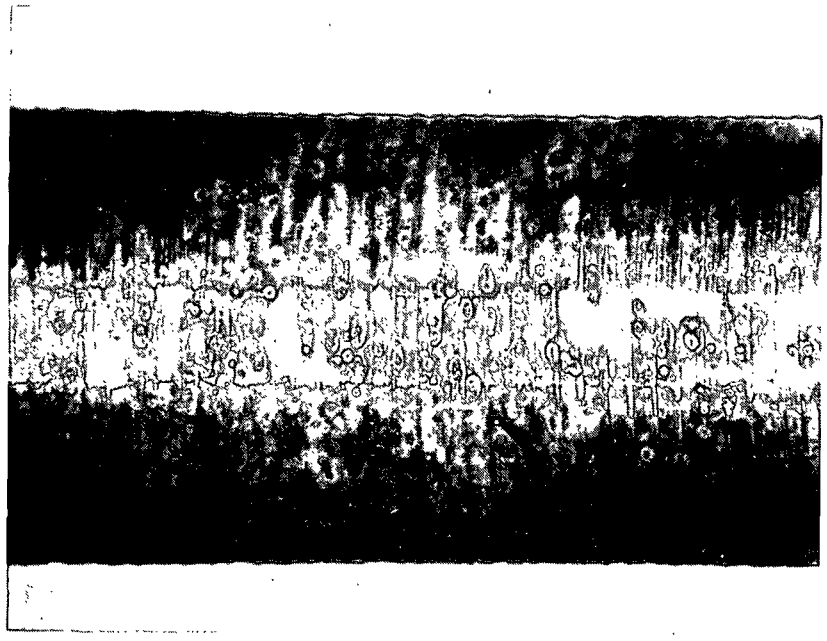
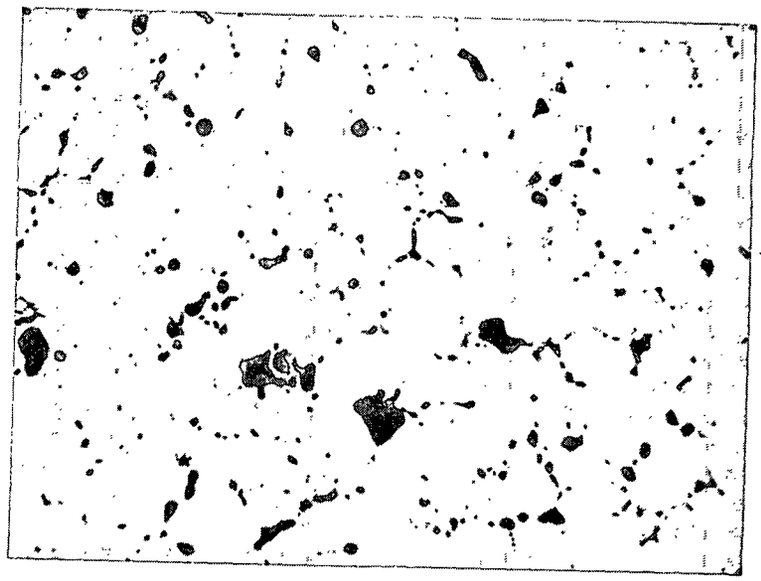


Figure 22. Appearance of CA-15 test specimen after anodic polarization test in WWI water, 0.3 v/hr., 55°C. (9X)

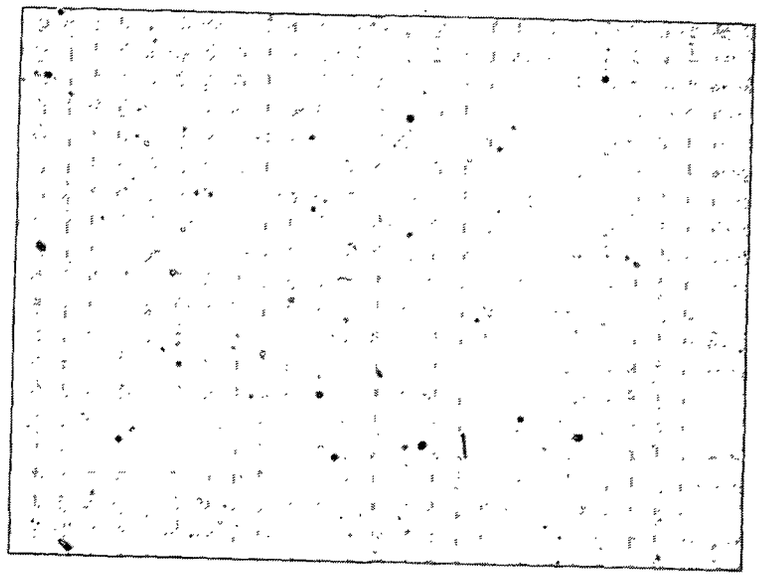
Several important implications for future work are noteworthy as a result of the above tests and observations. First, regarding surface defects, it is possible that the test blocks are not representative of the roll shell. The test block is removed from the end of the centrifugal casting which is normally discarded in the manufacture of the finished roll. This piece, due to location in the casting process, may contain more impurities and porosity than the roll. Second, if the test block is representative, some or all of the defects could be attributed to the machining process used to extract specimens from the block, i.e., the use of lathe and milling machine to produce surface finishes which are supposed to simulate twist drill and ream, or gun drilling operations. Finally, if the forged and continuously cast test blocks, in shipment, are taken from "defect free" locations in the shell and/or the currently observed specimen defects from castings remain unproven machining artifacts, an equitable evaluation in comparing corrosion resistance of alloys produced by these different manufacturing processes is questionable.

METALLOGRAPHY

Small strips, ca., 3/8 inches square, were sectioned from each alloy block so that the metal structure from o.d. to i.d. of the shell could be examined. While this activity is still in progress at the time of this writing, some of the results can be described. Figure 23 shows the unetched, polished condition of bronze and CA 15. The dark spots are primarily inclusions (oxide, sulfide impurities); the round, dark spots in bronze are lead particles and the large and integrated networks of dark spots are impurities, which segregate to dendritic grain boundaries during solidification. This appearance of bronze is typical and the impurities are reasons for its low strength properties.



IN Bronze



CA-15

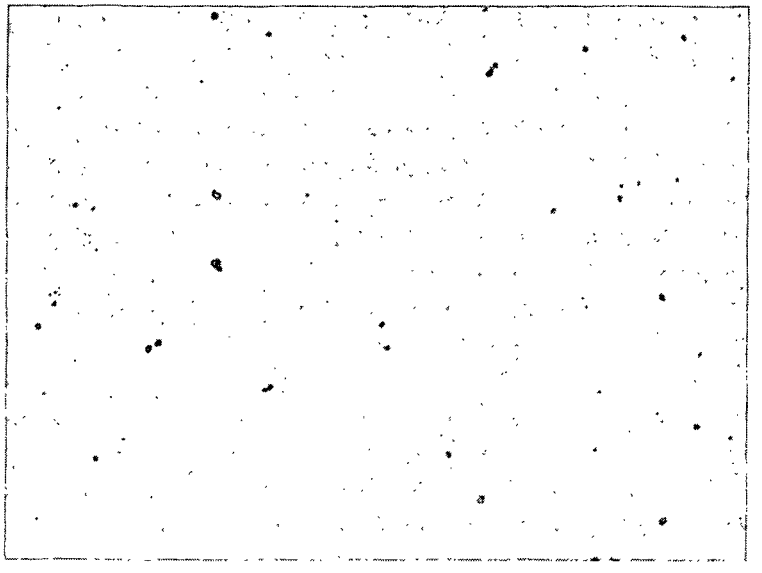
Figure 23. Metallographic appearance of bronze (top photo) and CA 15 (bottom photo) showing impurities inherent in these cast alloys. (Unetched, 50-X.)

The more rounded and fewer impurities in the stainless steel are shown in Fig. 24. Actually these appeared gray (typical of sulfide inclusions) under the microscope. The grain structure of these metals is shown in Fig. 25. In this case, the islands or blocks (darker color in A75) are austenite and the background or matrix is ferrite. The more ductile austenite blocks are barriers to crack propagation and this contributes to the higher strength properties in the duplex alloys.

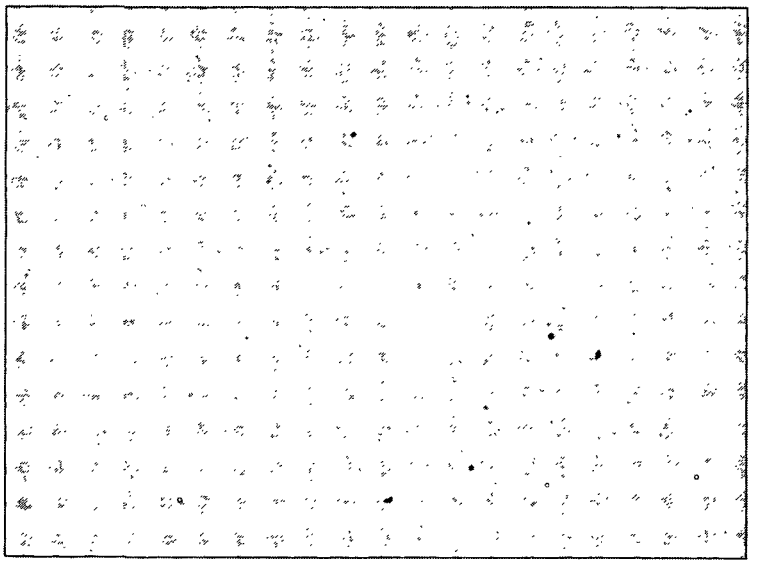
Although further metallography and scanning electron microscopy is in progress, this initial observation indicates the metals are relatively free of porosity. This is surprising in view of the multitude of macro-surface defects observed on as machined specimens, as reported above. Subject to further examination, this anomaly may be indicative of the lack of homogeniteity inherent with the casting process.

INVESTIGATION OF SHOT PEENING

The beneficial effect of shot peening to improve the fatigue life of metals is proven technology. As a follow-up to plans discussed at the last meeting, the interaction with Metal Improvement Company (MIC) has continued. Shot peening of the shell o.d. and i.d. poses no problem. As a first option, peening the shell i.d. will require some buffing after the peening treatment to preserve a 50 RMS, finish which was reported by three suppliers as the surface condition of the shell i.d. Eight coupons of each cast alloy, reported above, are currently being peened by MIC to establish procedures. These peened coupons will be assessed for corrosion resistance upon return to IPC. Cost estimates for common rolls are under study, but these should be available for verbal report in March.

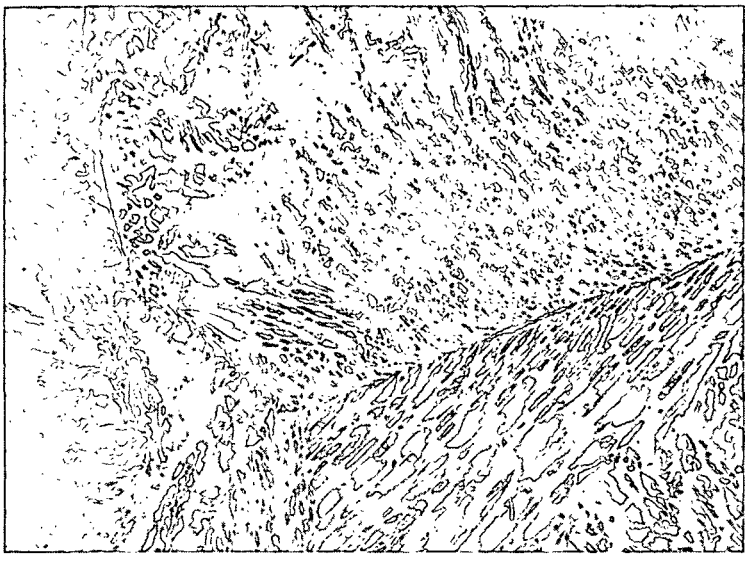


CF-3M

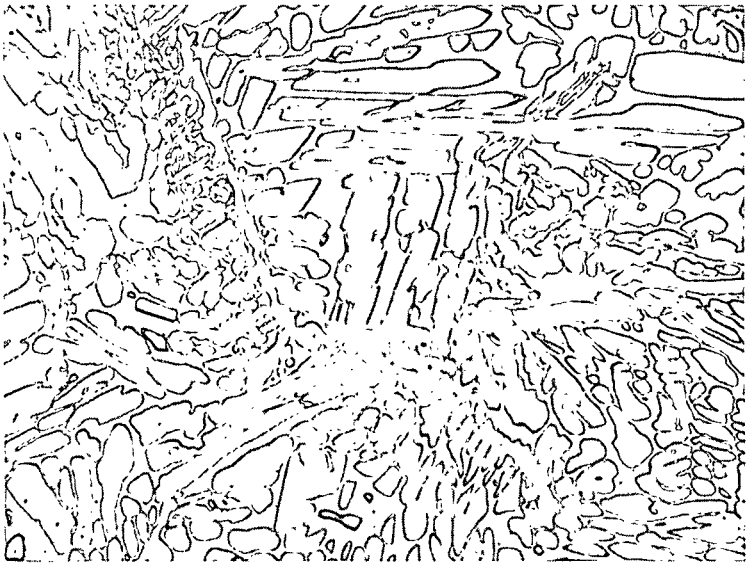


A-171

Figure 24. Metallographic appearance of impurities in stainless steel suction roll alloys. (Unetched, 50X.)



A-75



A-171

Figure 25. Microstructure of A-75 (top photo) and A-171 showing islands of austenite in ferrite matrix. A-75 Marble's reagent, 50X; A-171 electrolytic etch, aqua regia, 50X.

Through thickness penetration of suction holes by shot peening has recently been demonstrated with a new nozzle design. The demonstration was performed on sections of previously failed rolls provided by IPC and MacMillan Bloedel, Canada. Further developments and cost estimates will be presented in March.

As a separate activity, Mr. Paul Feld, (MIC), on his own, has pursued the possibility of burnishing the holes in a suction roll. An independent machine shop has taken sections of the failed rolls, mentioned above, and demonstrated the viability of this process. Compressive stresses several mils deep were imparted to hole surfaces throughout the shell thickness. An automated burnishing process is possible at a "ballpark" cost of 10 cents per hole. The cost, logistics, confidentiality, etc., for this process require further follow-up. Slides taken during both shot peening and burnishing operations should be available by March.

FUTURE WORK

Short Range: Evaluate the corrosion resistance of suction roll alloys.

(1) Resolve surface defect problem in order to evaluate cast alloys in-house.

- Send representative specimens back to machine shop to verify possibility of defects being artifacts of machining.
- Review appearance of surface defects with supplier(s) to define cause, i.e., casting defects, machining, etc.
- Investigate further, in-house microscopic and SEM, the nature of defects, i.e., inclusions, dross, holes (porosity).
- Sequentially inspect surface condition for defects, proceeding from as-machined to 120, 240, 400, 600 grit abrasive (emery) paper grinding.

(2) Continue corrosion tests on cast alloys.

- Selective tests in TAPPI I water to determine resistance of as machined specimens exposed to this less aggressive environments. Modify, if necessary.

Investigate.

- Smialowska's* technique to evaluate crevice corrosion resistance (protection potential) of AISI316L and, if successful, test suction roll alloys.

- Select both long term and accelerated tests to evaluate deposit/microbiological corrosion.

(3) Upon receipt of other alloys, e.g., forgings, continuous cast, etc., machine, inspect and test specimens in WWI white water.

(4) Continue investigation of shot peening and/or hole burnishing.

- Corrosion testing of shot peened coupons and non-peened coupons at 50 RMS finish.

- Machine and drill new pieces from suction roll alloy blocks, and send to MIC to peen and burnish for purposes of better characterization of peened and/or burnished hole surfaces; corrosion test to evaluate rate of loss of this surface, and/or corrosion resistance.

- Based on above results, machine and test corrosion fatigue (rotating beam) specimens of selected alloys in peened and non-peened condition.

- Update methods for shot peening and its appraisal for cost effectiveness in improving roll life for a given alloy.

(5) Finish literature review and publish progress report to membership.

Long Range (FY 1984/85):

(1) Completion of the evaluation of corrosion resistance of suction roll alloys.

(2) Installation and operation of Materials Testing System (MTS) Model 810 for corrosion fatigue tests.

(3) Begin corrosion fatigue studies of crack propogation in suction roll alloys.

(4) Further pursuit of methods to improve roll life by corrosion fatigue tests.

* Smialowska, S. The analysis of electrochemical methods for the determination of characteristic potentials of pitting corrosion. Corrosion Science, 11:901-14(1971).

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

Status Report

to the

ENGINEERING PROJECT ADVISORY COMMITTEE

Project 3556

FUNDAMENTALS OF KRAFT LIQUOR CORROSIVITY

February 10, 1984

PROJECT SUMMARY FORM

DATE: February 16, 1984

PROJECT NO. 3556 - Fundamentals of Kraft Liquor Corrosivity

PROJECT LEADER: R. A. Yeske

IPC GOAL: Increase the useful life of equipment by proper selection of materials of construction, and by identifying suitable process conditions.

OBJECTIVE:

Use electrochemical methods to understand the corrosion processes occurring in kraft process streams as the basis for timely detection and elimination of corrosion and corrosion-assisted cracking in the kraft pulp mill.

CURRENT FISCAL BUDGET: $130,000

SUMMARY OF RESULTS SINCE LAST REPORT: (October, 1983 - January, 1984)

The effort to identify reliable methods for early detection of high corrosion rates in kraft white liquors is continuing. Additional linear polarization (LP) studies in simulated liquors have shown that the linear polarization method is accurate if the carbon steel is actively corroding. The previously identified Tafel-constant term in the governing equation for the LP tests has been shown to be appropriate for several additional environments.

Electrical resistance probes are being evaluated as an alternative method of monitoring corrosion rates in kraft liquors. Preliminary indications are that the change in resistance of a corroding wire is an accurate measure of average corrosion rate in simulated white liquor. Artifacts associated with deposition of a conductive film have not appeared.

The potential of the silver/silver sulfide (SSS) reference electrode has been determined in several actual mill liquors and found to be unaffected by the presence of organic species derived from early pulping processes. An empirical equation for the dependence of the SSS potential on sulfide concentration is close to, but not exactly equal to, the theoretical curve.

Using the LP method and coupon weight loss measurements, the effects of white liquor composition on its corrosivity toward carbon steel are being evaluated. Current tests show that sulfide and hydroxide effects are small in the range relevant to white liquors. The previously reported acceleration of corrosion by low concentrations of dissolved polysulfides appear to be a transient effect, since long term exposures show that carbon steel is eventually passivated in solutions containing as little as 0.5 g/l S°.

An apparatus for determining the effect of liquor velocity on corrosion rates of carbon steel has been designed and built, and is being calibrated prior to coupon exposures. The apparatus will also permit LP studies of corrosion rate versus liquor velocity.

Two reports have been issued to the members of the Institute which describe the results of this project. The first deals with the SSS reference electrode and the second covers linear polarization studies in kraft white liquors.

FUNDAMENTALS OF KRAFT LIQUOR CORROSIVITY

INTRODUCTION

The overall objective of this program is to reduce the costs of corrosion and corrosion-assisted cracking of materials of construction in the kraft pulp mill. Corrosion damages pumps, valves, storage tanks, clarifiers, piping, digesters and other components exposed to the white, green and black liquors generated in kraft pulping. The high cost of corrosion of kraft liquor environments has long been recognized, but little has been done to control this form of damage, aside from replacement with expensive stainless steels.

Although many different corrosion-related problems occur in the various kraft liquors, the investigation is currently focused on the most severe of these problems — corrosion of carbon steel in white liquors. This form of corrosion damage seriously reduces the lifetime of clarifiers, storage tanks, piping and ancillary equipment used in the preparation and storage of white liquor. Next in priority is corrosion-assisted cracking of pressure vessel steels, which is targeted for study in the next fiscal year.

The study of corrosion of carbon steel in white liquors has been focused on two areas:

- Detection of excessive corrosion rates, and
- Understanding of the effects of liquor variables on corrosion rates.

The first of these topics is being studied because the corrosion rate in white liquor is known to vary considerably with time. The lowest corrosion rate

experienced by any component may be acceptable, whereas most of the corrosion damage occurs during periods of very high corrosion rate. Work is underway to qualify methods for on-line monitoring of corrosion rates in white liquors, so that mills can use these methods to detect periods of high corrosion damage in time to take remedial measures before extensive damage occurs. The second topic is being addressed because a change in process chemistry is the only credible source of day to day variation in corrosion rate in a white liquor stream. An understanding of the effect of composition, temperature, velocity, and wet/dry conditions will aid in the elimination of serious damage, once high corrosion rates are encountered.

In the present reporting period, research efforts have been focused on the following areas:

i) Examination of the effects of organic species on the SSS reference electrode.

ii) Further evaluation of the linear polarization method for on-line monitoring of corrosion rates in white liquor.

iii) Preliminary examination of the electrical resistance method of corrosion rate measurement in kraft liquors.

iv) Further characterization of the effect of liquor species on the corrosivity of white liquor toward carbon steel.

v) Preparation of two reports for members of the Institute.

Although the studies are not yet complete, the results of this study provide considerable insight into the corrosion process in white liquors.

RESULTS

SILVER/SILVER-SULFIDE REFERENCE ELECTRODE

The attractive attributes of the SSS reference electrode have been described in previous status reports to the Engineering Project Advisory Committee. The

SSS electrode has been shown to be a stable, easily fabricated, directly immersible reference electrode that maintains a stable potential when exposed to liquors of constant sulfide concentration. The stability of the SSS electrode potential during changes in inorganic liquor composition has also been documented in earlier reports.

In the present reporting period, the stability of SSS rest potential was determined during exposure to several liquors extracted from actual mill process streams associated with continuous digester operation. The sampled process streams included make-up liquor at the make-up liquor pump suction, top circulation liquor, impregnation zone liquor and upper cook zone liquor, all of which contained organic species derived from low temperature cooking processes in the continuous digester. The concentrations of the major species in these liquors were known from a companion program and are tabulated in Table I. Silver/silver-sulfide electrodes were exposed to these liquors for periods as long as one month, while daily measurements were made of the SSS potential versus the Calomel electrode.

TABLE I

COMPARISON OF INORGANIC COMPOSITIONS

Mill #	Liquor Extraction Site	NaOH	Na_2S	Na_2CO_3
1	Upper Cooking Zone	22	13	29
1	Top Circulation Line	58	17	25
2	Upper Cooking Zone	14	21	17
3	Top Circulation Line	73	26	22
3	Make-Up Line	59	29	22

The SSS potential was consistently higher in organic-laden liquors than in inorganic liquors of similar sulfide concentration, but the difference was small (10mV). In Fig. 1, the data for tests in actual liquors are superimposed on the scatterband of the SSS data shown in the previous status report. From this study, the reference potential of the SSS electrode can be considered to be independent of organic concentration in typical cooking liquors for all but the most exacting electrochemical tests.

The dependence of the SSS potential on sulfide concentration is accurately described by the Nernst equation for the reaction

$$2Ag + S^{=} \rightleftharpoons Ag_2S + 2e^{-}, \qquad (1)$$

which is given as

$$E_{SSS}\ (VSHE) = -0.7125 - \frac{RT}{nF}\ \ln\ (a_S) \qquad (2)$$

where n = the number of electrons transferred in a reaction event (=2),

F = Faraday's constant,

R = the gas constant,

T = the absolute temperature, and

a_S = the activity of the $S^{=}$ ion.

Taking the temperature to be 90°C, and assuming a pH of 14 and an activity coefficient of one, equation 2 becomes

$$E_{SSS}\ (VSHE) = -0.7125 - 0.036\ \log\ (\frac{[Na_2S]}{858}) \qquad (3)$$

where $[Na_2S]$ is the concentration of Na_2S in grams/liter. However, the agreement is somewhat better between the data and the following empirical equation

$$E_{SSS}\ (VSHE) = -0.7125 - 0.039\ \log\ (\frac{[Na_2S]}{858}) \qquad (4)$$

This empirical curve is shown as the solid line in Fig. 2.

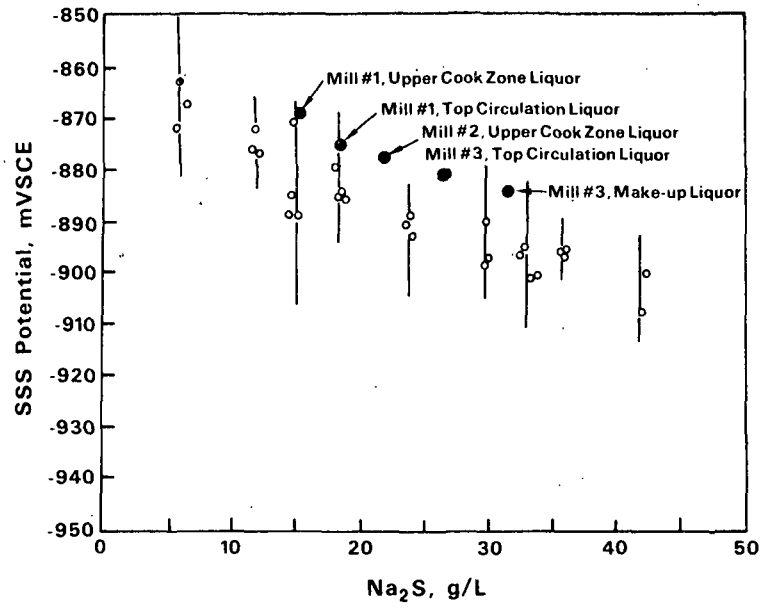


Figure 1. Effect of organic species on the SSS reference potential at 90°C.

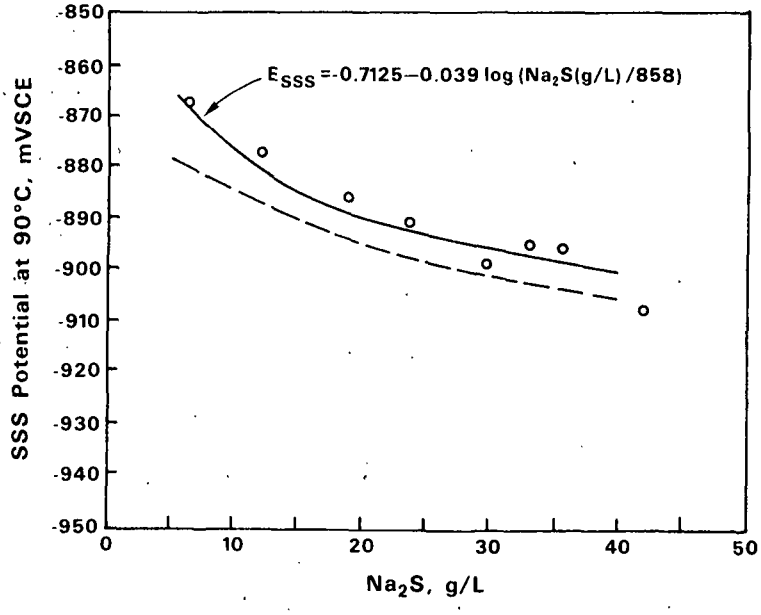


Figure 2. Empirical (solid line) and theoretical (dashed line) representations of the dependence of the SSS potential on [Na_2S] at 90°C.

LINEAR POLARIZATION STUDIES

The effect of liquor composition on the accuracy of the linear polarization method was further investigated by considering the effects of sodium sulfide, sodium polysulfide, and sodium hydroxide concentrations on liquor corrosivity measured by weight loss and LP methods. The approach used was the same as that described in previous reports — namely, concurrent measurements of corrosion rate by LP and coupon weight loss methods during an exposure to the simulated liquor for a period of approximately 400 hours. The solutions employed had NaOH concentrations in the range of 60-140 g/L, and Na_2S concentrations in the range of 15-50 g/L, which spans the credible range for white liquor. As in the preceding status report, the (β^*/Z) values required to bring the results of the LP measurement into agreement with the weight loss results were tabulated for each exposure condition.

In all of the environments tested, the (β^*/Z) value required for agreement between the LP and weight loss tests was in the range of 12-16 mV/decade. The results are shown in Table II. This is about one-third of the 41.65 mV/decade value that is programmed into the LP instrument used (Petrolite Model 1010), and the output from this instrument should be reduced by a factor of approximately three for maximum accuracy. Changes in liquor composition had little effect on the corrosion rate measured by LP or weight loss over the range of compositions considered. The average corrosion rate was approximately 5mpy in these solutions, which may be a consequence of a restricted electrolyte capacity for polysulfide reduction in a limited volume of solution. The rest potential of the test specimens remained at -240 to -250 mVSSS throughout the exposure, which is interpreted as a manifestation of the predominance of the hydrogen evolution reaction in the cathodic process (as opposed to a polysulfide reduction reaction that could support higher rest potentials and higher corrosion rates).

TABLE II

COMPARISON OF CORROSION RATES BY WEIGHT LOSS AND LINEAR POLARIZATION

Liquor (g/L) NaOH	Na_2S	Ave. Corrosion Rate (wt.loss - mpy)	Ave. Corrosion Rate+ (LP)	(β^*/Z) (mV)
60	33	4.4	12.4	14.6
80	33	5.9	15.7	16.1
100	33	5.3	16.1	14.3
120	33	5.4	17.5	13.6
140	33	5.0	16.6	13.2
60	20	4.2	11.5	15.8
60	40	4.0	12.1	13.6
140	40	5.0	17.6	12.6
100	15	4.0	12.9	15.0
100	20	4.4	12.6	15.9
100	25	4.9	14.1	15.0
100	30	4.8	15.9	13.4
100	35	4.2	15.0	11.7
100	40	4.4	14.9	12.9
100	45	4.4	13.0	14.6
100	50	4.4	14.0	13.5

+ These linear polarization measurements of corrosion rates are not corrected for the required adjustment in (β^*/Z) in the governing LP equation.

* (β^*/Z) is the Tafel constant term required to bring LP and weight loss results into agreement.

A series of tests were conducted to determine whether the anomalous results of LP tests in high-polysulfide liquors (reported previously) could be removed by subtracting the apparent corrosion rate observed on an adjacent inert electrode subjected to the same LP test. Inert stainless steel electrodes were subjected to LP tests in several high polysulfide liquors, together with carbon steel electrodes subjected to LP tests. Weight loss measurements indicated that the corrosion rate of the stainless steel was negligible in these tests, while the carbon steel corroded at a rapid rate in solutions containing low amounts of

excess sulfur (<1.5 g/L as S°). The carbon steel exposed to polysulfide solutions containing 1.5-2.0 g/L excess sulfur became passivated soon after immersion and resembled stainless steel in potential and actual corrosion rate.

From the LP tests on carbon steel and stainless steel in the solution containing 2 g/L of excess sulfur, it was clear that the errors in predicting the corrosion rate of carbon steel in high polysulfide solutions could not be removed by subtracting the apparent corrosion rate determined by the same LP technique on an adjacent inert electrode. In this environment, the carbon steel and the stainless steel were both passive, exhibiting rest potentials of approximately +110 mVSSS. Weight loss measurements showed that neither material was subject to significant corrosion during the exposure. As previously observed, the LP results indicated an apparent corrosion rate of 17 mpy (uncorrected for β^*/Z) on carbon steel, apparently due to redox reactions on that surface. On the stainless steel, where the same redox reactions established the same open circuit potential, the LP measurement showed a rate of only 2.5 mpy. Subtraction of the 2.5 mpy in inert stainless steel from the 17 mpy on steel will not significantly reduce the error of the LP result for carbon steel. Apparently, the surfaces of carbon steel and stainless steel have substantially different exchange current densities for the redox reactions that establish the potential. Consequently, the errors of the LP measurement on passive steel surfaces cannot be expunged by conducting companion LP tests on stainless steel and subtracting the common contribution to corrosion rates caused by redox effects.

ELECTRICAL RESISTANCE MEASUREMENT OF CORROSION RATE IN WHITE LIQUORS

Tests are being conducted to validate the use of Electrical Resistance (ER) methods for monitoring the rate of corrosion of carbon steel in white liquor. This method is actually an electrical resistance measurement of loss of current carrying cross section of a wire (or a similar thin-section coupon) because of corrosion. As the wire corrodes in the liquor, the resistance will increase because the cross-sectional area of the conductor decreases, and this change in resistance can be determined by placing the corroding wire in a resistance bridge and balancing the bridge. A Rohrback Model 4100 Corrosometer is being used to follow corrosion rates in the laboratory using simulated liquors. The Corrosometer Probe is Type W-40, a 1010 steel wire with a diameter chosen to optimize probe sensitivity and probe element lifetime.

In a preliminary exposure in simulated liquor containing 100 g/l NaOH and 33 g/L Na_2S, there was good agreement between the ER tests and actual weight losses by companion weight loss coupons exposed to the same liquor. In a 285 hour exposure, the average corrosion rate by weight loss was 14.2 mpy (+0.4,-0.6 mpy) for 1018 carbon steel, whereas the ER test predicted a corrosion rate of 13.1 mpy. Anticipated problems with conductive sulfide deposits formed on the wires did not materialize in this liquor, but testing is underway to demonstrate the accuracy of the ER method in other liquors. If the ER method is verified for use in white liquors, it may be a practical alternative to the linear polarization method that avoids the inherent errors which occur when the LP tests are employed in high polydulfide liquors.

VELOCITY EFFEECTS ON CORROSION RATES IN WHITE LIQUORS

A flow channel has been constructed to examine the effects of liquor velocity on the rate of corrosion of carbon steel. This flow channel will expose

the surfaces of multiple cylindrical coupons to liquors flowing at different velocities in the annular region between the coupon and a section of pipe. Flow velocities are determined with a paddle wheel flow sensor. Liquor temperatures are maintained by immersing the entire flow channel in a steam heated water bath. Initial tests will involve weight loss measurement only, but subsequent tests will incorporate simultaneous LP and ER measurements of corrosion rate, as well.

EFFECTS OF SOLUTE SPECIES ON CORROSION RATES IN KRAFT LIQUOR

Weight loss tests and complementary polarization curve generation are being used to characterize the effects of different solute species on the corrosivity of white liquor toward carbon steel. To date, tests on binary solutions containing only Na_2S and NaOH have demonstrated little difference in corrosion rate over the range of compositions encountered in actual white liquors. The average corrosion rate has been approximately 5 mpy in these tests. However, the experimental design is such that the concentration of oxidizing species in these tests has been very low, so that the only reduction process has been reduction of water to form H_2 gas.

In a new series of tests, the effects of polysulfides on liquor corrosivity are being determined over long term exposures. Preliminary indications from these tests show that polysulfides present at very low levels (0.5 g/l S°) will induce passivation with cessation of active corrosion after prolonged exposure (8 weeks). In previously reported short-term tests, the low concentrations of polysulfide have only increased the rate of active corrosion. Current long-term tests suggest that low concentrations of polysulfide may not be as damaging as earlier, short-term tests indicated.

SIGNIFICANCE TO THE INDUSTRY

Tests on the SSS electrode continue to demonstrate the usefulness of this electrode as a reference for voltage measurement in electrochemical studies. The current results show that organic species present in the early stages of the kraft cooking process do not significantly affect the SSS reference potential, so the electrode should also be useful in kraft process streams containing significant levels of wood-derived organic species.

The linear polarization method continues to show promise as a tool for early detection of excessive corrosion rates in white liquor. The LP method is most accurate when the carbon steel is experiencing high levels of corrosion damage. Under conditions where the carbon steel is passive and corrosion rates are low, redox reactions in the liquor can masquerade as corrosion of the steel; however, this anomaly can always be detected by a simple measurement of the rest potential of the steel. Simple subtraction of the apparent corrosion rate measured by LP methods on a companion stainless steel coupon will not remove the error detected in high polysulfide liquors.

The electrical resistance method of monitoring corrosion rates of carbon steel in white liquors shows considerable promise, based on early tests. Anticipated problems caused by conductive deposits have not materialized.

The long term effects of polysulfide on corrosion rate appear to be different from those observed in short term tests, so that low levels of polysulfide may not be as damaging as generally acknowledged.

Two reports have been written for member company use, based on the results of this study. The first, entitled "The Silver/Silver Sulfide Reference

Electrode for Use in Corrosion Studies in Kraft White Liquor", describes the results of the investigation of the characteristics of the SSS electrode and also provides a "how-to" manual for use and interpretation of potential measurements in white liquor. The second report describes, for the non-specialist, the basis of the linear polarization method and its use in monitoring corrosion rates in white liquors. This second report is entitled "Corrosion Rate Measurements in Kraft White Liquor".

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

Status Report

to the

ENGINEERING PROJECT ADVISORY COMMITTEE

Project 3384

REFINING OF CHEMICAL PULPS FOR IMPROVED PROPERTIES

February 10, 1984

PROJECT SUMMARY FORM

DATE: February 10, 1984

PROJECT NO. 3384 - Refining of Chemical Pulps for Improved Properties

PROJECT LEADER: J. D. Sinkey

IPC GOAL: Enhance our understanding of refining.

OBJECTIVE:

To advance our knowledge of refining which will lead to one or more of the following benefits:

- reduce capital, operating and/or maintenance costs of the refining process;
- increase paper machine drainage and speed, while maintaining or improving sheet formation, uniformity and strength;
- alter fiber properties in a specified manner to improve and control sheet properties.

CURRENT FISCAL BUDGET: $105,000

SUMMARY OF RESULTS SINCE LAST REPORT: (October, 1983 - January, 1984)

Theoretical consideration of the stress on a single fiber element has led to expressions for refining severity which account for many of the factors not addressed in classical specific edge load theory. Parameters taken into account in deriving these relationships include fiber length and coarseness, consistency, bar angle, height, length and width, and extent of flocculation on bar edges. A key variable is seen to be the local normal pressure on a bar segment. The analysis indicates that suitable measurement of this parameter (its mean and its distribution) may provide the means to control fiber stresses within the window of optimum fiber development. Theories are put forth which indicate that fiber cutting and fines generation may be predictable through the derived expressions. A program is proposed to test the theories, and to carry out the in-refiner pressure measurements. The work has great potential impact in refining control strategy, especially with sensitive species like hardwoods, and in the specification of the precision of refining machinery.

REFINING SEVERITY

INTRODUCTION

Previous work on this project has aimed at a general understanding of the mechanics of refining, especially with respect to which various types of refining actions tended to produce various refining effects (external fibrillation, internal delamination, fiber cutting, fines generation, etc.). The effort has included studies of the influence of rotor speed on energy consumption, and investigations of certain novel refining approaches. These latter studies included the use of abrasive refining surfaces, and work with a so-called roll refiner. The roll refiner, which applied primarily compressive forces to a fiber mat, produced internal delamination as the chief effect. From this work, one can conclude that different types of refining action (compression, shear, etc.) do indeed favor certain types of fiber modification.

It seems evident that a primary goal of this project ought to be to gain predictive control of the type of fiber modification which will be brought about by refining. That is, we would like to be able to specify and control the refining conditions (things like specific edge load parameters, force levels, etc.) which will give optimum pulp properties, as a function of several considerations. One of these considerations, of course, is the set of papermaking and end-use properties which is desired. For example, if drainage rate (fines content?) is critical, or if tear strength (fiber length?) is very important, how do we change the refining to meet the requirements? Our present state of knowledge does not allow us to either very well describe or bring about the changes that ought to be made in refiner design or operation to meet such specifications.

Another of these considerations is fiber type. Southern pine, spruce, and hardwoods all require different refining treatment, but we are unable to quantify it, or even tell for sure what fiber properties make them different. The pulp history (recycled vs. virgin, e.g.) and pulping process are other variables which affect refining response. How do we control refining to get the desired pulp properties from kraft vs. sulfite vs. high-yield stocks? Or alternatively, could we, by proper refining control, utilize a lower cost fiber source?

When refining is carried out with more severe impacts, fiber cutting and fines generation tend to increase at relatively low specific energy input. Unfortunately, the available descriptions of refining severity account for only a few of the factors known to promote these (usually) undesirable fiber changes. In considering the control of fiber response to the type or intensity of refining, it seemed to us necessary to first consider the stress encountered by an individual fiber. Knowledge of the factors which affect individual fiber stresses is needed, to maintain those stresses at levels which produce desirable fiber modifications, but below levels which lead to undesirable fiber damage.

In the following is an account of some theoretical considerations of the shear and tensile stresses on a single fiber element in a refiner. As a result of this effort, we have obtained expressions for shear and tensile stress on a fiber, which account for many of the factors not encompassed in classical specific edge load theory. We have also advanced hypotheses which would predictably relate, through these equations, such things as fiber length and density, consistency, bar angle, gap, etc., to fiber cutting and undesirable rapid fines generation. An experimental program is proposed to test these theories.

BACKGROUND

In conventional low-consistency refining of chemical pulps, the fibers receive impacts by bar crossings, at up to 30 kHz frequency. The refining may be quantified by two independent functions:

1. The amount of refining (the number of impacts per fiber) determines the extent of fiber modification. It is typically expressed as specific energy:

$$E_{net} = \frac{P}{qC}, \tag{1}$$

where P is net power consumed (exclusive of "no-load"),

q is volumetric flow rate,

C is stock consistency.

2. The type or intensity of the impacts determines the character of the refining action on the fibers. That is, it affects the relative amounts of external fibrillation, internal delamination, fiber cutting, fines generation, etc. Refining severity has been quantitatively expressed in terms of specific edge load:

$$SEL = \frac{P}{\Omega Z_r Z_s L}, \tag{2}$$

where Ω is the relative rotational speed of the discs,

Z_r and Z_s are the numbers of bars on the two discs,

L is the average bar length.

THE UTILITY OF SPECIFIC EDGE LOAD

Presumably, the difference between gentle and severe refining relates to the plastic vs. elastic nature of the deformations. As a viscoelastic material, the pulp may respond to gentle impacts by absorbing much energy elastically,

with little bond breakage per impact. This would maximize the "desirable" refining outcomes - internal delamination, external fibrillation, etc. - albeit with high elastic energy absorption. Very severe impacts, on the other hand, may tend to shatter the fiber, eliciting much cutting and fines formation, with relatively little energy consumption.

For greatest energy efficiency, then, it is desirable to operate at the highest level of SEL which the fiber can withstand without unacceptable pulp property deterioration. To this end, variable speed drives have been used to accomplish independent control of SEL (1), as discussed in connection with previous work on this project.

Figure 1 compares the effects of varying SEL in the refining of a hardwood and a softwood pulp, in terms of energy efficiency and pulp strength development (2). The application of a given level of specific energy as more severe impacts (higher SEL) increases the tendency to fiber cutting for both pulps, although the hardwood is more sensitive in this regard. The effect of SEL on the development of drainage resistance, however, is the opposite for the two pulp types. That may reflect a difference in the type as well as the amount of fines generated by more severe refining of the hardwood, as compared to the softwood. Hence, the more severe level of 4 Ws/m affords an attractive energy savings with only a small loss in properties with the pine, but it virtually destroys the birch pulp.

This illustrates that the ultimate results of increased refining severity depend on the fiber's characteristics - its response to different degrees of abuse. It is further apparent that the control of refining severity is especially critical for hardwood pulps. Clearly there is a need for greater

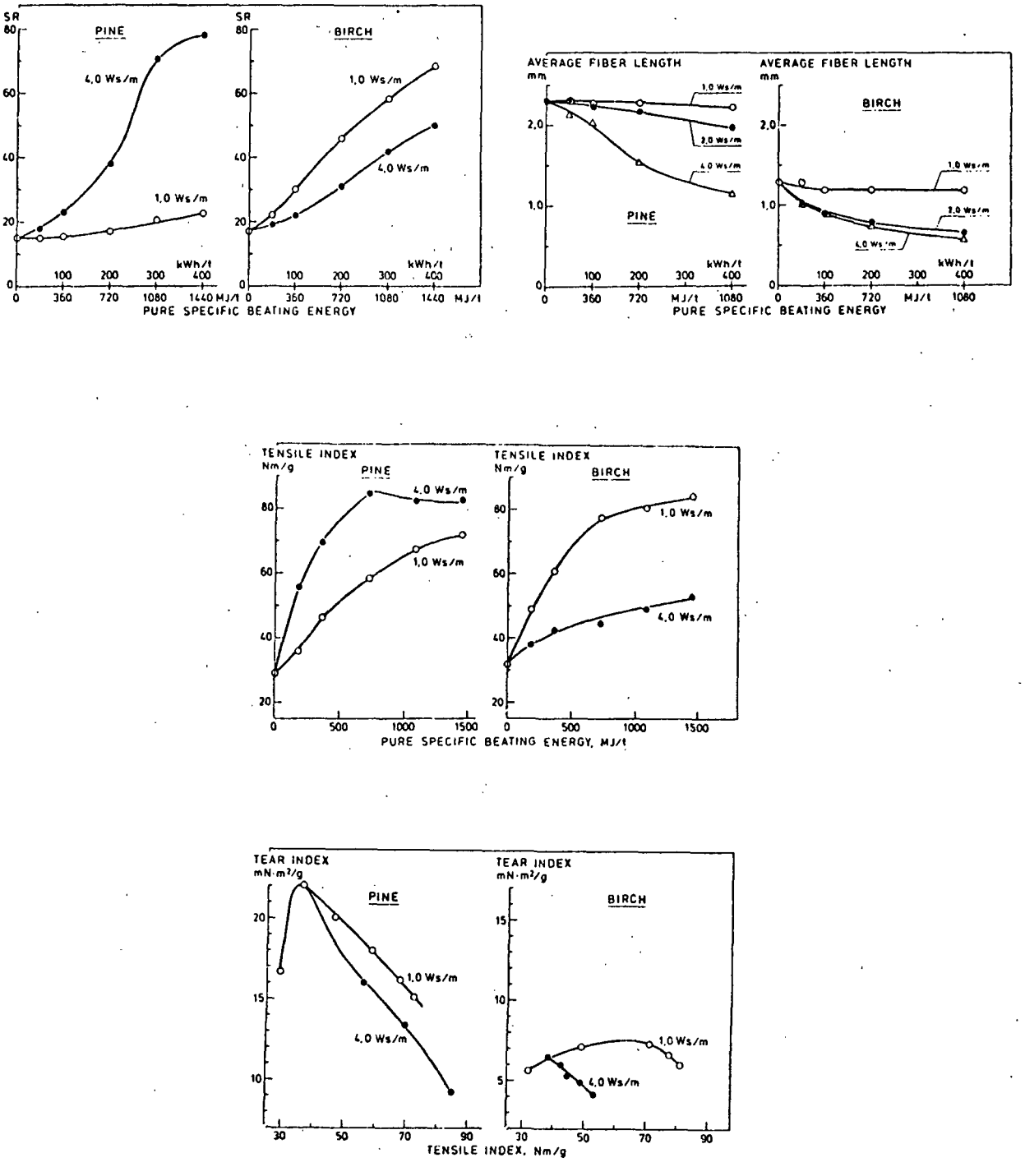


Figure 1. Properties of bleached pine and birch kraft pulps at various levels of specific edge load (from Ref. 2).

understanding of the factors which affect refining severity - their mechanism of action, their measurement and control. Such knowledge is essential if we are to obtain maximum benefit from such sensitive pulps as hardwoods.

LIMITATIONS OF SEL

The specific edge load concept has proved very useful, both in clarifying the effects of certain design parameters of bar-filled refiners, and in providing guidelines for refiner control. However, it is not a comprehensive theory for characterizing refining and predicting the results. For instance, experience has shown that all the following parameters not considered in SEL, can influence refining intensity: bar angle, bar material, bar sharpness, groove depth, and consistency. The SEL concept has also been criticized for putting so much emphasis on the impact phenomenon of bar crossings: several refiner designs operate efficiently without edge-load type impacts. Included among these are basalt tackle refiners, and the Vargo refiner (3). In addition to these shortcomings, of course, is the lack of consideration of fiber characteristics. Specific edge load theory offers no explanation for the different responses of longer fibers or hardwood/softwood differences.

Several workers have attempted to develop more comprehensive refining severity models, notably by deriving expressions for energy per impact. Among the more recent of these is that of Leider and Nissan (4), who expressed energy per impact in the form

$$E = \frac{(E_{net}\ \frac{\text{energy}}{\text{kg}})(M\ \frac{\text{kg}}{\text{fiber}})}{(\text{impacts/fiber})}. \qquad (3)$$

They derived an expression for the denominator which could be written:

$$\frac{\pi^3}{4}\left(\frac{D_m}{w}\right)^3 L\,\frac{\Omega}{q}\,\ell_f\,d_f,$$

where D_m = mean diameter of refining zone,

w = mean width of bars and grooves,

ℓ_f = average fiber length,

d_f = average fiber diameter.

Substituting this and Eq. (1) into Eq. (3) yields an "energy per impact" expression:

$$E = \frac{4PMw^3}{\pi^3 C D_m^3 L \Omega \ell_f d_f}. \quad (4)$$

If we assume both plates have the same pattern, then

$$Z_r = Z_s = \frac{\pi D_m}{2w}, \quad (5)$$

and Eq. (2) may be written

$$SEL = \frac{4Pw^2}{\pi^2 D_m^2 L \Omega}. \quad (6)$$

Comparing Eq. (4) and (6) indicates that Leider and Nissan's "energy per impact" expression has incorporated consistency C, fiber parameters ℓ_f, d_f, and M, and an additional "Z" term [Eq. (5)] in the denominator. Equation (4) says that refining is more severe with coarser or denser fibers ($M/\ell_f d_f$), and at lower consistencies - if everything else remains the same.

STRESS ON A SINGLE FIBER

Even if we assume that such additions to the SEL concept as those of Leider and Nissan do correctly model other effects, much is still lacking. The influences of many of the parameters which affect refining intensity have not been described. Moreover, the mechanism of fiber shortening, or of low-energy fines generation by shattering impacts, are not directly addressed in any of the previous models. Hence, the ability to predict the prevalence of those phenomena

depends on empirical correlations, with conclusions not applicable in a very general sense. It is needful to express refining severity in terms of the stress experienced by individual fibers. Then, depending on the pulp's visco-elastic properties, this would directly relate to the strain - the fiber response. Controlling fiber stress levels in a refiner implies the ability to control fiber shortening, and the amount (and perhaps type) of fines generated from it vs. internal and external fibrillation, etc.

A knowledge of factors which affect average fiber stress, and the maximum stress levels encountered, are both necessary. During its course through a refiner, a fiber endures many impacts with a distribution of stress levels. The probability of its suffering undesirable damage depends not only on the average stress level over the whole refiner, but also on the frequency of encountering impacts with stress above a critical level. An objective of this effort would be to gain the capability of measuring and controlling stress levels within the desirable window - to maintain stress distributions with an average level high enough to economically effect useful fiber modification, while minimizing the frequency of damaging levels. This could lead to improved refining control strategies tailored to the raw material (hardwood vs. softwood, etc.) and the end-use requirements. In addition, there may be implications concerning the level of refiner precision, tram, and other operating conditions needed to maintain narrow stress distributions for sensitive pulps.

NORMAL STRESS

The work of Goncharov (5), in measuring the pressure on individual bars during refining, has provided evidence that the work of refining occurs only on the leading portion of the bar width, up to a distance about equal to the

average fiber length $\overline{\ell}$. He reported normal pressures near the bar leading edge as high as 3500 kPa (ca. 500 psi). This was more than an order of magnitude higher than the measured thrust divided by bar contact area. Trailing portions of the bar generally experienced pressures of 10-15% of the maximum normal pressure P_N. The pressure profile during the bar crossing was almost a step function: it was maintained at a nearly constant P_N value from distance 0 to $\overline{\ell}$ across the bar, then quickly dropped to a much lower value across the rest of the bar width.

Examination of the data of Goncharov (5) has led this writer to suggest that, at least at "reasonable" levels of refining severity, and when $w > \overline{\ell}$, $\overline{P_N}$ times the area over which it is exerted ($\overline{\ell}Z^2L$), is equal to the thrust on the disk, T:

$$\overline{P_N}\,\overline{\ell}Z^2L = T. \tag{7}$$

This can be expressed in terms of power P rather than thrust by employing an overall friction coefficient μ: $2P/D_m\Omega = \mu T$. Substituting:

$$\overline{P_N} = \frac{T}{Z^2L\overline{\ell}} = \frac{2P}{\mu D_m \Omega Z^2 L \overline{\ell}} \tag{8}$$

Bar sharpness (plate wear) probably influences the value of μ.

We might assume that the stapled fibers are squeezed together in that leading-edge work zone, such that there is a continuum of pressure being experienced by the fibers in the stapled mat. Then the normal pressure on a fiber increment $d\ell$ equals P_N, the compressive stress on the fiber. Hence, the normal force being experienced by a fiber increment of width w_f and length $d\ell$ is

$$dF_{Nf} = P_N\, w_f\, d\ell = \frac{w_f T d\ell}{Z^2L\overline{\ell}} = \frac{2w_f P d\ell}{\mu D_m \Omega Z^2 L \overline{\ell}} \tag{9}$$

FIBER STRESS IN OTHER DIRECTIONS

The work of Hartman (6) has demonstrated that compressive stresses applied to fiber mats can produce desirable internal delaminations, and impart fiber flexibility, when applied at fairly uniform levels of about 500 psi. This compares well with the compressive stress levels recorded in refiners by Goncharov (5), as mentioned above. However, Hartman's compressive forces produced very little fines or external fibrillation. When applied at levels of about 1500 psi (10,000 kPa), excessive fiber damage and cutting resulted.

These and other observations lead us to put forth the following postulates concerning "undesirable" refining outcomes:

- Fiber cutting can directly result from excessive normal or compressive stresses, perhaps at a level near 10,000 kPa for softwoods.
- The majority of fiber shortening, however, is a result of failure of the fiber in tension, within the stapled mat in the compression zone.
- The generation of excessive and choppy fines at low energy levels arises from high shear stress levels in the stapled mat.

Corollaries to these postulates may be stated in connection with "desirable" refining outcomes: reasonable levels of compressive stress promote kneading and internal delaminating, and reasonable levels of shear stress promote external fibrillation. In order to minimize the negative results, however, we must more closely examine shear and tensile stresses on the fiber level.

SHEAR STRESS

Considering our fiber increment of length $d\ell$ and width w_f, the force in the tangential direction is

$$dF_f = \mu_f \, dF_{Nf} = \mu_f \, P_N \, w_f \, d\ell, \qquad (10)$$

where μ_f is the local interfiber coefficient of friction (perhaps different from

the overall coefficient μ). Then the shear stress is

$$\tau_f = \frac{dF_f}{w_f d\ell} = \mu_f P_N \tag{11}$$

Substituting Eq. (8):

$$\overline{\tau}_f = \frac{\mu_f T}{Z^2 L \overline{\ell}} = \frac{2(\mu_f/\mu)P}{D_m \Omega Z^2 L \overline{\ell}} \tag{12}$$

Equation (12) says that pulps with shorter average fiber length (hardwoods?) experience higher average shear stress at a given thrust or power level. It also contains the specific edge load terms, predicting effects identical to classical theory. If the postulates above are correct, then the primary effect of these things would be seen in fines and debris production, rapid freeness drop, etc.

FIBER TENSILE STRESS

If the compressed thickness of our fiber segment is t_f, then the tensile stress in the segment is

$$d\sigma_f = \frac{dF_f}{w_f t_f} = \frac{\mu_f P_N \, d\ell}{t_f}. \tag{13}$$

Assuming that t_f does not change much with the amount of compression, then the cross-sectional area of the compression zone which is filled with fiber equals $t_f w_f N$, where N is the number of fibers under compression in the whole refiner. This cross-sectional area can also be expressed in terms of the gap δ and a factor $\overline{f}$:

$$t_f \, w_f N = \overline{f} \delta L Z^2. \tag{14}$$

The term $\overline{f}$ is the fraction of the entire gap which is filled with fibers. The introduction of this term is consistent with Ebeling's floc theory (7), which

poses the possibility that stapled fibrage may not be distributed uniformly along the bar length.

The number of fibers in the refiner under compression N is the product of several terms:

$(\frac{C}{M}$ fibers/unit volume)(2hwLZ refiner volume)(p)

$\times$ $(\frac{\text{bar crossing area } w^2/4}{\text{refining area } \pi D_m^2/4})$($\ell$/w ratio of compression zone to bar crossing area),

where h is the bar height, and p is the probability that an average fiber will be stapled. If p equals the ratio of gap cross-section to refining zone cross-sectional area, times the ratio of fiber area to gap area:

$$p = (\frac{2w\delta}{2wh})(\frac{A_f}{2w\delta}) = \frac{A_f}{2wh}, \tag{15}$$

where A_f is the projected area of a fiber as it enters a compression zone in the gap (length times uncompressed thickness). Then

$$N = \frac{CLZw\bar{\ell}A_f}{\pi M D_m^2} \tag{16}$$

Combining Eq. (5), (13), (14), and (16) yields

$$d\sigma_f = \frac{2\mu_f P_N C w^2 w_f A_f \bar{\ell} d\ell}{\pi^2 M \delta \bar{f} D_m^3} \tag{17}$$

Integrating, while ignoring any dependence of $\bar{f}$ on ℓ:

$$\bar{\sigma}_f = \frac{2\mu_f P_N C w^2 w_f A_f \bar{\ell} \ell}{\pi^2 M \delta \bar{f} D_m^3}, \tag{18}$$

where $\bar{\sigma}_f$ and $\bar{P}_N$ are averages over the time in the refiner. The mean refining

diameter may be expressed in terms of the disk diameter D and the angle θ between the bars and a radius: $D_m = D - 1/2 L\cos\theta$. Substituting this and Eq. (8) into Eq. (18) gives the expression for average tensile stress on a fiber of length ℓ:

$$\overline{\sigma_f} = \frac{\mu_f T C \ell}{2Z^4 L (M/A_f w_f) \overline{\delta f} (D - 1/2 L\cos\theta}} \tag{19}$$

or in terms of power:

$$\overline{\sigma_f} = \frac{(\mu_f/\mu) P C \ell}{Z^4 L \Omega (M/A_f w_f) \overline{\delta f} (D - 1/2 L\cos\theta)^2} \tag{20}$$

If this expression is a reasonably valid representation of the average tensile stress experienced by a fiber in refining, then it should relate to the fiber shortening rate, as described by Corte and Agg (8). They reported that the shortening rate was a linear function of fiber length in a refiner. Equations (19) and (20) are consistent with this, although any dependence of $\overline{f}$ on average fiber length $\overline{\ell}$ is unknown.

In agreement with classical SEL theory, Eq. (20) predicts more cutting at higher power levels, lower disk speed, and with fewer (or wider) bars. This expression also indicates a tendency toward more fiber cutting with less slippery fibers (pH effects on μ_f, e.g.), and with bar crossing angle θ. Given the relationship between θ and D_m, this effect is consistent with specific edge load and energy per impact formulas, Eq. (4) and (6), although the exponent of D_m is different. However, Eq. (20) shows the opposite effect of consistency C, and average fiber density, $M/A_f w_f$, compared with Eq. (4). The consistency effect is particularly puzzling, since conventional wisdom says that more cutting results from lower consistency refining. Brown (9), however, has reported increased cutting in a beater when the consistency was increased from 1 to 2%.

The consistency discrepancy may be related to an effect on flocculation. Lower consistency may be associated with a greater variance of local "basis weight" of fiber over the refining area. The refiner would not be as full of fiber so there would be more flocculation. This in turn would probably relate to a higher variation of P_N, which could increase the frequency of encountering damaging stress levels even if $\overline{\sigma_f}$ were lower. In discussing his flocculation theory, Ebeling (7) stated that "flocs may be under a compressive stress of well over 10 MPa. It is interesting that Hartman (6) found that very level of compressive stress to be quite damaging to softwood fibers.

In this analysis, the very simplest relationship was assumed between P_N and net power P [Eq. (8)]. Presumably this relationship would be affected by several of the factors which SEL does not address, such as bar sharpness, and bar material or surface characteristics.

FUTURE WORK

In order to test certain aspects of the foregoing, two areas of effort are proposed:

1. It would be useful to develop the capability of measuring P_N in a refiner. This would enable us to:
   - compare the magnitude with the results of Goncharov (5) and Hartman (6);
   - test Ebeling's floc theory (7) by determining the random variation of P_N with time;
   - study the importance of refiner gap variation (tram, taper, wobble, etc.) on P_N and stress distributions, by examining P_N variations at frequencies of impact and disk revolution, and variations at different locations in the refiner;

- establish the relationship between power or thrust and P_N as a function of several variables, including those unexplained by classical SEL theory;
- correlate calculated tensile stress on fibers σ_f (and number of impacts) with fiber shortening rate for hardwoods and softwoods, to test the hypothesis that σ_f directly affects cutting as a function of pulp viscoelastic properties;
- similarly correlate calculated fiber shear stress τ_f with fines production rates and fiber and fines specific surface changes to test the hypothesis regarding excessive τ_f levels.

Accordingly, the means for measuring P_N, the local pressure on bar leading edges, are presently being developed for the S-W Twin-Flo refiner.

2. In a parallel effort, a program is being developed to test other aspects of the model equations for $\overline{\tau_f}$ and $\overline{\sigma_f}$, with respect to the predicted effects of the various parameters on cutting, type and amount of fines, etc. Pulp characteristics to be varied include pulp coarseness and type (hardwood vs. softwood), and consistency. Beating or refining will be carried out, at different levels of severity, on pulps spiked with dyed or tagged fibers of a narrow fiber length range. The determination of the quantitites of tagged material in the various fiber length and fines fractions of the refined pulp will indicate how much fiber shortening and fines production was experienced by fibers of that length range.

ULTIMATE BENEFITS

If P_N could be easily measured in industrial refiners, it may constitute a superior refining control parameter. The objective of measuring and controlling refining severity has great potential impact on control of energy consumption,

pulp drainage rates, and strength development. This is particularly true in the refining of hardwood pulps, which are especially sensitive to severe refining conditions.

An improved understanding of the factors which affect the rate of fiber shortening and fines production may also prove particularly useful in avoiding the frequency of reaching damaging fiber stress levels. By narrowing the distribution of stresses at a given average stress level, we may be able to avoid much damage to sensitive pulps such as hardwoods, while still developing desirable fiber characteristics. As mentioned before, such factors as refiner precision, tram, taper, plate wear, and floc distribution (as affected by consistency) and how "full" the refiner is run, may prove to be critical.

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

Status Report

to the

ENGINEERING PROJECT ADVISORY COMMITTEE

Project 3480

WET PRESSING FUNDAMENTALS

February 10, 1984

PROJECT SUMMARY FORM

DATE: February 16, 1984

PROJECT NO. 3480 - Wet Pressing Fundamentals

PROJECT LEADER: N. L. Chang

IPC GOAL: Fundamentally increase the potential capacity of processes.

OBJECTIVE:

To develop a comprehensive understanding of the wet pressing process through the measurement of water removal rates and the dynamic responses to a pressure pulse of felts and paper under dynamic conditions.

CURRENT FISCAL BUDGET: $140,000

SUMMARY OF RESULTS SINCE LAST REPORT: (October, 1983 - January, 1984)

The project objectives have been reviewed and changed, as noted above, from pursuit of incremental improvements in wet pressing to the development of concepts that have breakthrough potential. Planning, materials selection, and procedures for the comparative study of felts and porous plates have been completed. Valid comparative results should be available shortly. Exploratory experiments on displacement pressing have been carried out to show that high dryness levels can be achieved without using any thermal energy. These results confirm the technical feasibility of displacement pressing. We will now begin collecting data to determine engineering and economic feasibility. Displacement pressing offers tremendous advantages in dryer loads, energy costs, productivity, runnability, paper properties, and so on.

WET PRESSING FUNDAMENTALS

INTRODUCTION

Recent past work on this project used the press-nip simulator to study the viscoelastic properties of felts and sheets, and for direct evaluation of water removal as a function of pressing conditions and sheet properties. Such work is important in that it provides some of the fundamental information required to design better presses. However, improvements deriving from such an approach are likely to be incremental in nature, leading to small increases in nip effectiveness or sheet dryness. Institute research more typically places emphasis on high risk projects that have a correspondingly high potential for improvements of major or breakthrough proportions. With this in mind, we have reviewed and redirected this project toward two broad new objectives. Attainment of these objectives could lead to large energy savings, productivity increases, and property improvements in papermaking. These objectives are: (1) increased pressing efficiency, and (2) pressing to higher dryness. The first objective is related to promoting increased water removal for a given press impulse, through improvement of the water-receiving system; the second is primarily related to the use of new water removal concepts that go beyond the traditional ideas of wet pressing. During this reporting period, work was initiated on both of these objectives.

HIGH EFFICIENCY PRESSING

BACKGROUND

Figure 1 [replotted from Ceckler and Thompson (1)] shows press exit dryness levels (total water removed) as a function of press impulse for a typical furnish and basis weight sheet. For sheets with less than 45-50% dryness, these

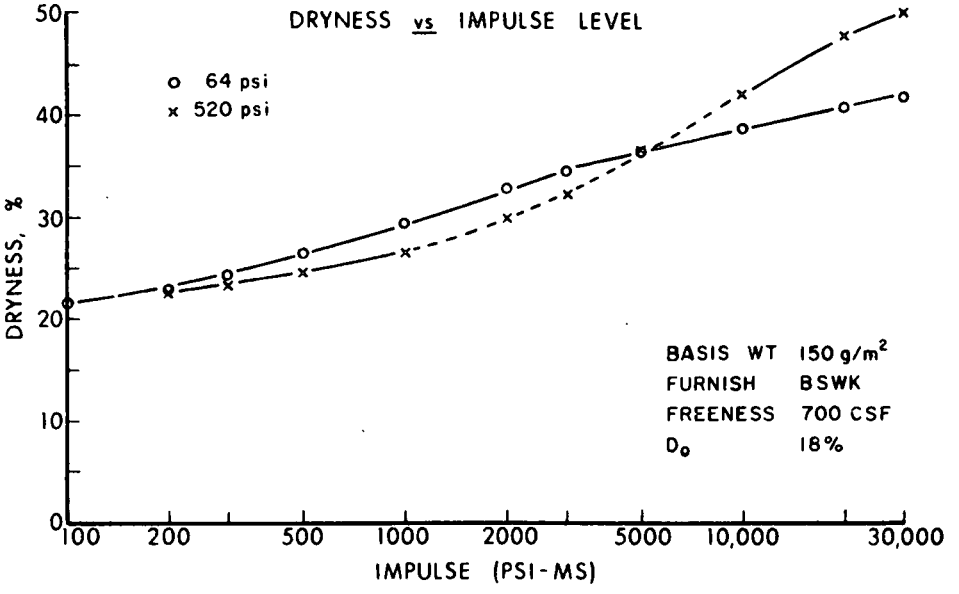

Figure 1. Effect of pressure.

and other data clearly show that press impulse is the dominant controlling variable. In this regime, pressure and time are largely interchangeable with the absolute level of pressure playing a small role. For higher dryness levels, impulse loses its dominance and pressure and other variables become important. These zones are often referred to as "flow controlled" (impulse controlled) and "compression controlled" (pressure controlled), respectively. Current extended nip technology provides impulse levels that nearly span the flow controlled range and can lead to dryness levels around 50%.

In their DOE sponsored wet pressing study, Ceckler and Thompson (1) performed a number of experiments in the flow controlled regime to compare laboratory and pilot press performance. The laboratory unit used porous metal plates to receive the water whereas the pilot press used a felt. Under some test conditions, the laboratory press removed almost twice as much water as the pilot

press for a given impulse level. Ceckler and Thompson attributed the greater effectiveness of the laboratory press to the uniformity of pressure provided by the porous plate as opposed to great variability in local pressure delivered by the felt. Conclusive evidence for this hypothesis was not given, however.

Whatever the cause of the performance difference, the finding is very important. These data suggest that substantial improvements in press performance may be possible if we can supply a proper pressing and water receiving system. Improving press effectiveness (water removed per unit of impulse applied) would lead to the following benefits:

a. reduction in pressing system capital and operating costs, e.g., two presses instead of three

b. higher production rates on machines that are not dryer limited

c. higher dryness levels out of some presses with corresponding improvements in dryer loads, wet web runnability, and sheet density.

Our research in this area is designed to confirm and capitalize on this finding.

RESEARCH PLAN

The work on high efficiency pressing will proceed, initially, in two steps: (1) confirmation of the UMO results, and (2) determination of the water-receiver characteristics required to achieve the higher efficiencies. The resulting data should be sufficient for design of equipment for a laboratory demonstration of the concept.

Confirmation Experiments

For several representative cases (various combinations of sheet basis weight and freeness, initial moisture ratio, applied impulse, etc.) water removal performance data will be obtained for the two types of water receivers

used in the UMO study: commercial press felts and porous plates. Use of a Wahren-Zotterman press simulator for tests on both water receivers will allow a direct and meaningful comparison to be made. These tests will provide the opportunity to corroborate the UMO finding (obtained on a special dynamic compression tester), that smooth porous plates effect more water removal than felts, in an apparatus that has been shown to provide a very good simulation of a real press nip. These results will help to define the range for which nip efficiency improvements are possible. They will also be used to identify the physical mechanisms that control pressing efficiencies.

Water-Receiver Properties for High Efficiency Pressing

If the confirmation experiments are successful in achieving high pressing efficiencies with selected water receivers, the next step will be to determine the characteristics of the receiver that control efficiency. Data collected in this process will satisfy three needs: optimization of press performance, engineering analysis and design of pilot and commercial equipment, and understanding of the physical principles involved.

To define the required water-receiver characteristics, pressing experiments will be conducted at selected sheet and pressing conditions representative of current practice. A variety of water-receiving materials will be tested to evaluate the importance of such parameters as compressibility, permeability (in the compressed state), surface smoothness (or scale of nonuniformity of pressure transmission), pore size/capillary pressure/moisture ratio relations, and wettability. The selection of candidate materials and parameters will be guided by experience and consideration of physical mechanisms of probable importance.

RESULTS TO DATE

Some preliminary experiments with felts and porous plates have been conducted, all with the intent of working out the experimental procedures. A number of porous plate and felt materials have been collected. Experiments aimed at producing valid comparative data will be initiated shortly.

DISPLACEMENT PRESSING

BACKGROUND

The data in Fig. 1 show that increases in press impulse yield only small increases in sheet dryness when the sheet is in the compression controlled zone. The exact level of dryness at which the transition to compression control occurs depends somewhat on basis weight, freeness, and so on. But the point is clear; increasing impulse levels beyond those achievable with extended nip presses will have little impact on water removal/dryness for dryness levels above the 45-50% range. Pressing pressure has a small positive impact in this zone, but structural design considerations will preclude significant advances via this route. Based on all of these factors, it appears that major gains in sheet dryness out of the press will require a different pressing mechanism.

At high dryness levels, practical pressing pressures squeeze some water out of the fibers into the interfiber pores, but not enough to saturate the sheet. For this unsaturated condition, there is no hydraulic pressure gradient to drive the water from the sheet. In impulse drying, we have a similar state of sheet compression and saturation. Here, however, appreciable liquid water removal is induced by the bulk flow of the vapor generated at the hot surface. In pressing at high dryness levels, we can invoke the same mechanism by driving air or steam

through the sheet from an external source. As the gas stream flows through the compressed sheet, a portion of the available water is removed by displacement or entrainment. This mechanism can be used to raise sheet dryness levels well above those achievable with conventional or extended nip presses without using any thermal energy. For the moment, this concept will be called "displacement pressing."

EXPLORATORY EXPERIMENTS

A simple displacement press chamber (Fig. 2) was constructed for obtaining preliminary data on the dryness levels attainable by displacement pressing. In this simple chamber, the wet sheet is sandwiched between two drilled plates which act as load spreaders while allowing air and water to pass. Various combinations of screens, felts, and porous plates are placed between the sheet and the load spreaders. For the initial experiments, the chamber assembly was placed in a static press to provide compression of the sheet. Compressed air

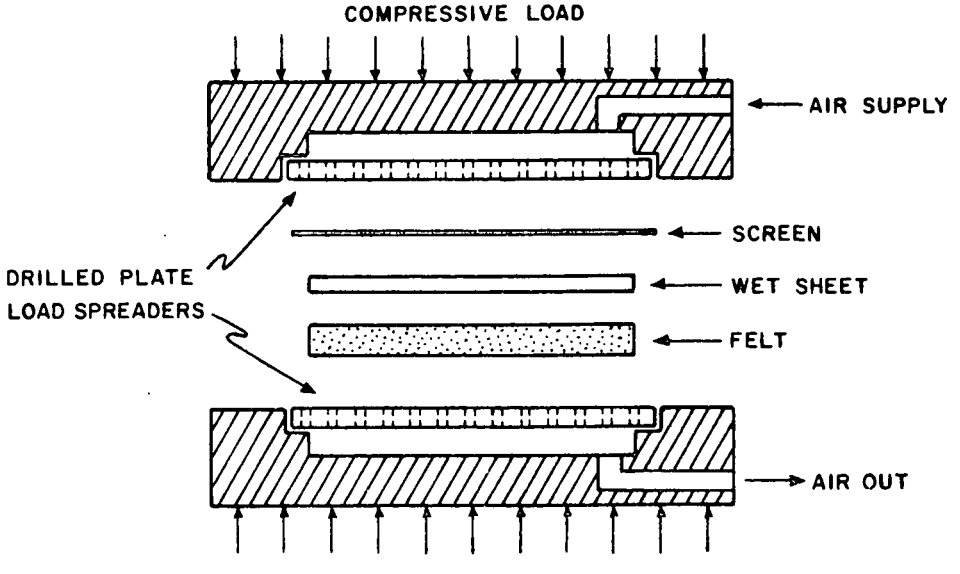

Figure 2. Displacement press chamber.

was then passed through the sheet for a predetermined period of time to displace the water.

Test sheets of 125 g/m^2 basis weight were prepared from unrefined bleached kraft softwood pulp at a CSF of 720. Initial moisture content was set at about 48%. For the initial experiments, compression pressure, displacement pressure, displacement time, and the materials adjacent to the sheet were varied.

From these limited experiments, we make the following observations:

1. Sheet dryness levels of 60-65% were readily achieved. A few experiments resulted in higher values.
2. Over the range from 300 to 600 psi, compression pressure had no effect on water removal.
3. Increasing displacement pressure or time increases sheet dryness, apparently in a somewhat interchangeable fashion. Dryness levels of 61-62% were achieved in two seconds or less. Improving the very poor sheet seals in our simple press should improve this result.
4. Providing proper load and air distribution over the sheet appear to be important although our experiments are far from conclusive. To date, best results have been obtained with a felt on one side of the sheet. In our manually operated system, the long elapsed time after pressing could lead to significant rewetting, thus rendering our results somewhat pessimistic.
5. The component of water removed due to pressing alone is small compared to that removed by displacement. This is the expected result for relatively dry sheet.

All of the above results are in the expected direction and consistent with our understanding of the processes involved except for the insensitivity to sheet load. We have no explanation for this at the moment.

Our drop-weight press simulators are now being modified to permit displacement pressing experiments in the time frame typical of real pressing operations. The new equipment will also give better sheet sealing. Results from these experiments will be important in determining the engineering and economic feasibility of the process.

ADVANTAGES OF DISPLACEMENT PRESSING

In preliminary experiments, we have demonstrated the technical feasibility of displacement pressing by achieving sheet dryness levels of 65% or more. Carefully designed equipment is expected to yield even higher dryness values. If displacement pressing proves to be economically feasible as well, it will offer the following advantages:

1. Higher press exit dryness will lower dryer loads and dryer energy costs, per unit of product, perhaps by as much as 50%.
2. For an existing dryer section, displacement pressing can be used to increase production rates.
3. For a specified production rate, displacement pressing will allow use of a much smaller dryer section with a correspondingly lower dryer capital cost.
4. Higher dryness levels will give higher wet web strength for better runnability. Constant or reduced adhesion levels should also result. This is in contrast to hot pressing, where the increase in web strength resulting from increased dryness is offset by the decrease in strength

from increased temperature. Adhesion levels also increase with temperature. Hence, displacement pressing should offer a substantial advantage over hot pressing from both a maximum dryness and runnability point of view.

5. Dry sheet density and strength properties are expected to increase, but this has yet to be proven.
6. Displacement pressing of relatively wet sheets (30-45% dryness) at low compression pressure may result in dry, bulky sheets, an advantage for some grades. Hence, by introducing displacement as a new pressing element, we may be able to exercise more control over final sheet properties than is now possible.

FUTURE WORK

We have already demonstrated the technical feasibility of displacement pressing. Our next immediate task is to determine if the high dryness results can be achieved under conditions that are reasonable from a cost and engineering point of view, and if they have a desirable impact on paper properties. We will be initiating experiments of this type very shortly. Following the demonstration of engineering and economic feasibility, we will initiate a technical performance evaluation of the process.

We have submitted a proposal to DOE for a small contract to pursue the objectives outlined at the front of this report. We are optimistic that the contract will be awarded soon.

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THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

Status Report

to the

ENGINEERING PROJECT ADVISORY COMMITTEE

Project 3470

FUNDAMENTALS OF DRYING

February 10, 1984

PROJECT SUMMARY FORM

DATE: February 14, 1984

PROJECT NO. 3470 - Fundamentals of Drying

PROJECT LEADER: F. W. Ahrens

IPC GOAL: Reduction of the "necessary minimum" complexity (number and/or sophistication) of process steps.

OBJECTIVE:

Develop an understanding of the physical mechanisms controlling the removal of water from a moist web under various boundary conditions typical of proposed new concepts and use this knowledge to identify drying conditions that may result in reduced energy use, utilization of low-grade energy, increased drying rates, and/or a favorable impact on paper properties. Evaluate the potential of advanced-concept drying systems.

CURRENT FISCAL BUDGET: $150,000

SUMMARY OF RESULTS SINCE LAST REPORT: (October, 1983 - January, 1984)

High intensity drying performance and mechanisms have been investigated for an intermediate range of mechanical pressures (5-300 psi). The drying rate increases more rapidly with pressure at high pressure levels, suggesting the possible importance of liquid water removal as the impulse drying regime is approached. Vapor pressure measurements at these conditions confirm that a large driving force (e.g., 10-100 psi) for liquid and vapor flow is available in the sheet at high surface temperature and mechanical pressure operating conditions.

Total water removal and liquid water removal have been measured over a range of impulse drying conditions, for surface temperatures up to 800°F. It is found that, under high pressure and temperature conditions, more than 40% of the total water removal from a 100 g/m^2 sheet can occur in the liquid phase. This has significant energy implications.

A tentative paper grade/furnish/properties test matrix has been prepared to aid in the broad, systematic evaluation of advanced water removal processes. Using this matrix as a standard test set, a technical data base will be developed through tests over a range of operating conditions.

FUNDAMENTALS OF DRYING

INTRODUCTION

It seems surprising that a mature technology such as paper drying has a large potential for improvement. However, the high-intensity drying processes which are under investigation at The Institute of Paper Chemistry have indeed demonstrated great potential. Drying systems using these high-intensity processes will be significantly smaller and, hence, less costly than conventional systems, or they will allow increased production rates. Also, they will be more energy efficient. Impulse drying appears to have the greatest potential for reducing energy use, due to a thermally-induced liquid-phase dewatering action. Thermal/vacuum drying has potential for using low-grade, less-expensive energy, due to the reduced boiling point resulting from vacuum operation. Furthermore, these water removal methods may, through beneficial effects on paper properties, lead to improved products or perhaps new products. They should permit given product specifications to be achieved with a reduced quantity or quality of raw material. This would yield a further energy savings.

Most of the work to date in the project has been directed toward investigating the technical feasibility of high-intensity water removal processes and establishing a level of understanding of their mechanisms. In some of the most significant accomplishments we have:

1. Shown that impulse drying (a hybrid pressing/drying concept) can give two to three orders of magnitude greater drying rates and use much less energy (30 to 70%) than conventional drying.

2. Shown that thermally-induced vacuum drying can give an order of magnitude increase in drying rate and can use low-grade energy for drying.

3. Defined the heat and mass transfer mechanisms for high-intensity drying processes (including press drying, thermal/vacuum drying, and impulse drying):

- developed several experimental devices for drying studies.
- established a technique for measuring instantaneous heat flux to the paper and made other detailed measurements needed to understand and quantify the performance of high-intensity drying.
- developed successful mathematical models of high-intensity drying processes.

The primary objective of future work in this project is to extend the current understanding of high-intensity water removal principles to include the comprehensive data base required for their effective and efficient commercial application. Drying performance and paper properties data for a representative range of paper grades and fiber furnishes are needed for engineering studies, overall economic assessment, and to enable matching the various high-intensity concepts with proper applications. Technical questions relating to the design of water removal systems using these high-intensity processes must be answered. In addition, an overall technology assessment of the potential of advanced water removal systems is needed.

In this report, the elements of the overall plan for this project will first be reviewed. Then, results of recent and current work in the project will be presented. This will include presentation of a tentative paper grade/furnish/property test matrix which has been selected as a standard test set for characterizing and assessing advanced water removal processes, including both pressing and drying. Finally, the goals and plans for the next reporting period will be summarized.

LONG RANGE PLAN

Improved understanding, additional technical data, and technology assessments are needed to guide the development and application of the high-intensity drying principles investigated thus far in this project, and to encourage

successful commercialization of water removal systems based on these principles. The nature of the data and assessments needed to allow commercialization to proceed, and the tasks required to produce this information, have been reviewed. Based on these considerations, a long-range plan for the project has been formulated.

A diagram exhibiting the key elements of the project, and their interrelationships, is given in Fig. 1. For completeness, both past and future areas of effort are included. A brief description of the objectives of these project elements is as follows.

1. Exploratory and Feasibility Studies:

   Provide early information (via bench-scale experiments) on the technical feasibility of improving the water removal process by application of high-intensity concepts such as impulse drying and thermal/vacuum drying. Quantify the potential benefits of these concepts.

2. Investigation of Water Removal Mechanisms:

   Develop an understanding (via bench-scale experiments and mathematical modeling) of the heat and mass transfer processes governing water removal from the paper web under high-intensity operating conditions typical of impulse drying, thermal/vacuum drying, etc., to provide a basis for guiding the development and design of advanced water removal systems.

3. Technical Performance Data:

   Develop a base of technical data (still by means of tests at the bench scale) on drying performance, energy use, paper properties, etc., for a representative range of paper grades, fiber furnishes and operating conditions sufficient for identification and assessment of advanced water removal system opportunities.

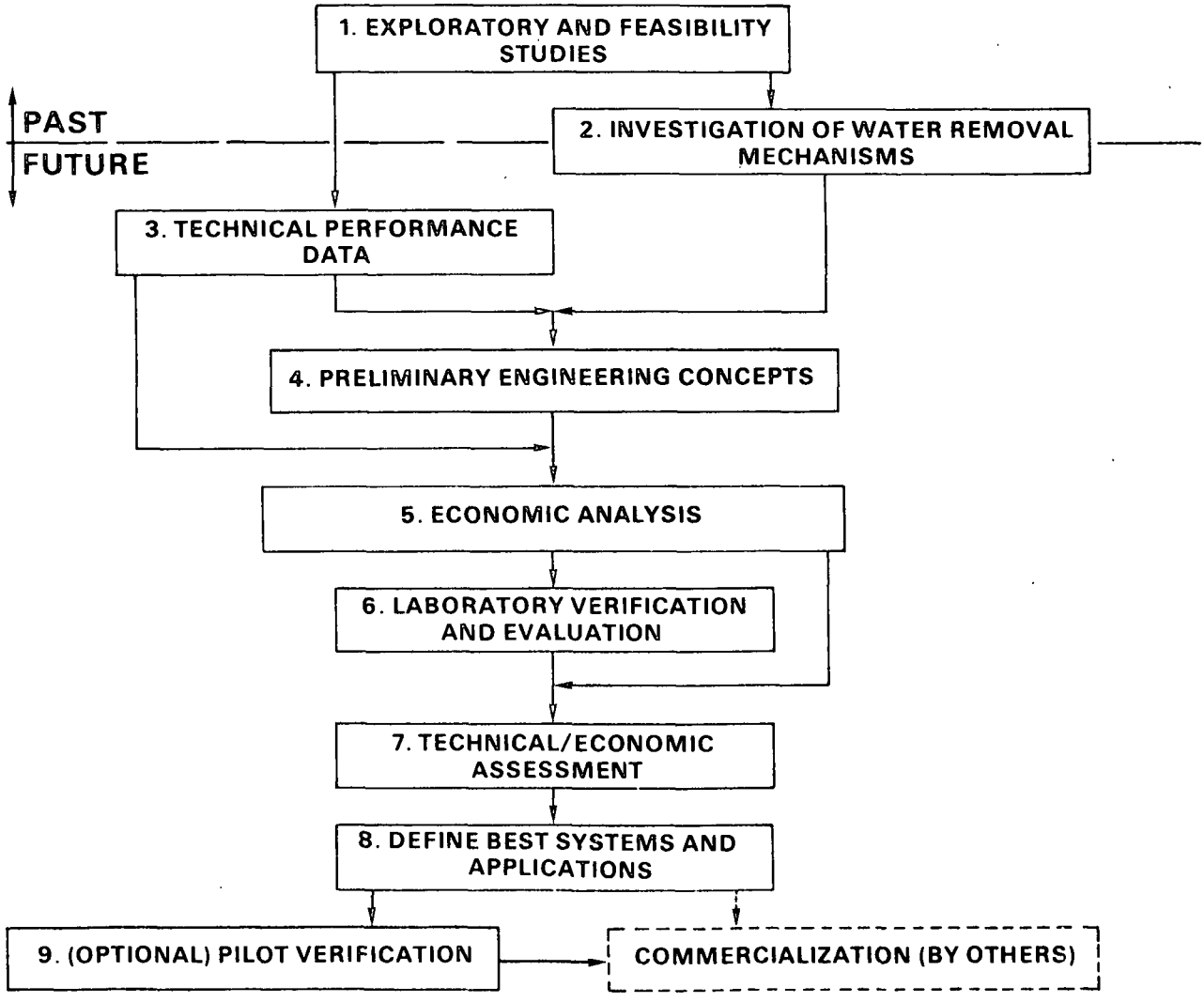

Figure 1. Long-range project elements.

4. Preliminary Engineering Concepts:

   Utilize the technical data gathered in Task 3 to establish preliminary system configurations (i.e., hardware requirements, size estimates, heat source options, etc.) appropriate for the various paper grades.

5. Economic Analysis:

   Develop capital and operating cost estimates for the various system concepts which are applicable to each paper or board grade and select those applications worthy of future work. This analysis should include the mill-wide impact of higher drying rates, smaller equipment, and use of different energy forms and rates.

6. Laboratory Verification and Evaluation:

   For the most promising systems and grade applications, develop laboratory scale systems (moving web) to verify their general validity, confirm the magnitude of benefits to be expected, and identify operating constraints and resolve problems not discernable at the bench scale.

7. Technical/Economic Assessment:

   Use the technical data from the laboratory verification work to improve upon the definition of design alternatives for water removal systems suitable for important paper and board grades and evaluate the mill-wide technical and economic impacts of these systems.

8. Define Best Systems and Applications:

   Develop and document the technical and economic data bases characterizing those water removal systems and applications having high payoff potential for the industry.

9. Pilot Verification (Optional):

   Design, construct, and operate pilot-scale version(s) of the best system(s), capable of high-speed, continuous web operation, to provide a more complete and accurate evaluation of the technical and economic impact of improved water removal technology, thereby stimulating the timely development of commercial equipment.

Funding has been requested from the U.S. Department of Energy to expedite the accomplishment of the work proposed in this long-range plan. About four years would be required. At this time, we have very positive indications but no firm commitments from DOE.

RECENT/CURRENT WORK

Most of the recently completed research and work in progress to be discussed in this section is related to program elements 1 and 2 in the long-range plan (see Fig. 1), although preliminary consideration is also given to the engineering and system implications of the data. Work dealing with the drying performance and mechanisms of high-intensity drying is first presented. Then, the results of work on water removal and energy effectiveness in impulse drying are considered. Finally, some engineering and system aspects of the impulse drying data are discussed.

HIGH-INTENSITY DRYING: PERFORMANCE AND MECHANISMS

Most of the atmospheric high-intensity drying experiments discussed in previous status reports for this project can be classified into two regimes of mechanical pressure application: constant pressure drying, at levels below 5 psi*,

*Pressures up to approximately 40 psi were employed in thermal/vacuum drying experiments.

and dynamic pressure during drying (as in a heated press nip), at average levels of 220 to 1760 psi. The typical water removal rates in the latter regime were found to be two to three orders of magnitude larger than those in the former regime. The latter, very high rate, mode of operation has been termed impulse drying. Within each of these regimes, it is found that increases in mechanical pressure cause increases in drying rate.

In an attempt to gain further insight into the mechanisms of high-intensity drying and the transition to very high water removal rates typical of the impulse drying regime (where a significant liquid-phase component of water removal is thought to occur), a series of experiments at intermediate (and constant) mechanical pressures (5-300 psi) has been performed. The drying rates occurring during these tests are displayed in Fig. 2. It is evident that the importance of mechanical pressure increases at high mechanical pressures. This is contrary to the "conventional wisdom," which is based on experience in the operating range for conventional dryers (see Fig. 2).

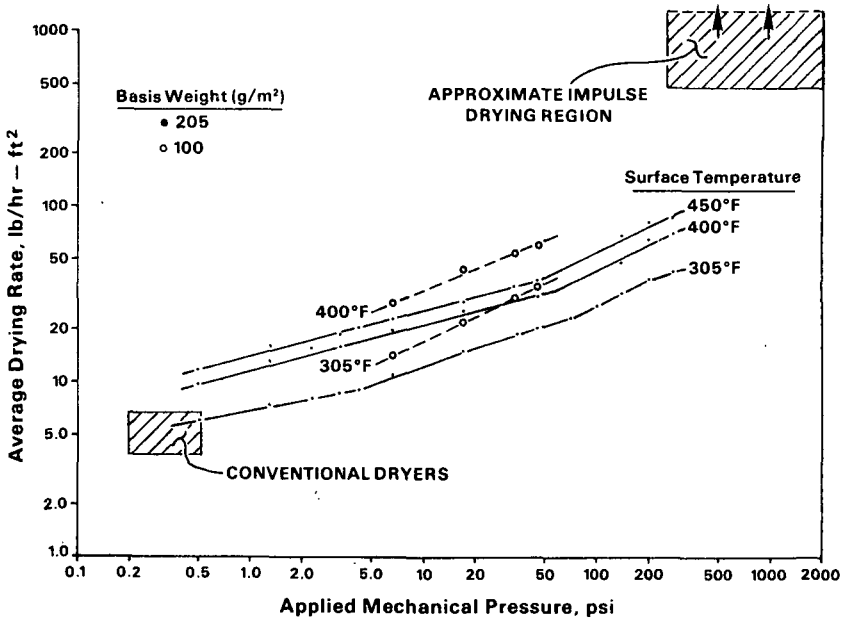

Figure 2. Average drying rate for unbleached softwood kraft handsheets with 60% initial moisture content, 6% final moisture content.

It should be noted that the pulp freeness (and thus the sheet flow resistance) has been found to have almost no effect on drying rate over most of the range of conditions (up to at least 50 psi) in Fig. 2. This is compatible with the simple two-zone model of high-intensity drying presented last year, in which heat transfer through a dry layer adjacent to the hot surface is considered to be the limiting step in the drying process. At very high mechanical pressures, however, the increased sheet compression would be expected to cause the flow resistance in the wet zone to take on more importance. An indirect consequence of this reasoning is that a gradually-increasing liquid-phase dewatering contribution (driven by increased vapor pressure in the sheet) would be expected to occur at the higher mechanical pressures. This contribution would help to explain the increasing slope of the curves in Fig. 2. A Ph.D. candidate, Joe Pounder, is extending the mathematical model to include the effects of flow resistance and liquid flow.

In spite of the factors just discussed, it appears from the data in Fig. 2 that the drying rates typical of true impulse drying (dynamic pressure) operation may exceed those in constant pressure drying, even at similar average pressure levels, temperatures, etc. If this is borne out, it would suggest that the pressure-time shape applied to the sheet during drying is an important "variable." Further exploration of this possibility is needed. Experiments by another Ph.D. candidate, Chris Devlin, at higher (but constant) pressures and temperatures may help to clarify the situation.

For many of the operating conditions corresponding to the data points in Fig. 2, the vapor pressure at the hot surface* and the surface temperature

*Note: Gage pressure, not absolute pressure.

response (used to compute the instantaneous heat flux and cumulative thermal energy transferred into the sheet) have been measured. Examples of the vapor pressure, heat flux, and energy transfer results are given in Fig. 3 through 5.

The vapor pressure is a significant quantity, since it is the driving force for vapor removal, and a major driving force for liquid flow, as well. The magnitude of the vapor pressure is governed by the vapor generation rate (essentially, the instantaneous drying rate, related to the instantaneous heat transfer rate to the sheet) and the flow resistance of the sheet to this vapor as it flows out to the surroundings. This statement is qualitatively confirmed by the similar shapes of the pressure and heat flux curves (Fig. 3 and 4). The peak pressures occurring at various freenesses and operating conditions are shown in Fig. 6. In general, the trends are physically reasonable; they also demonstrate that large driving forces for liquid-phase dewatering are developed at high temperature and mechanical pressure.

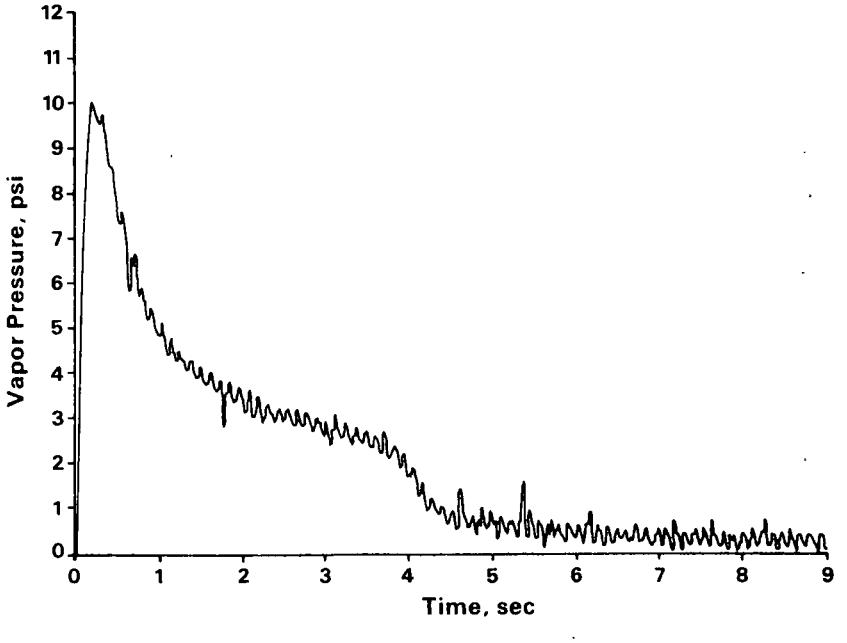

Figure 3. Vapor pressure at hot surface for unbleached softwood kraft handsheet, 205 g/m^2 basis weight, 60% initial moisture, 570 CSF, at 450°F surface temperature, 46.5 psi mechanical pressure.

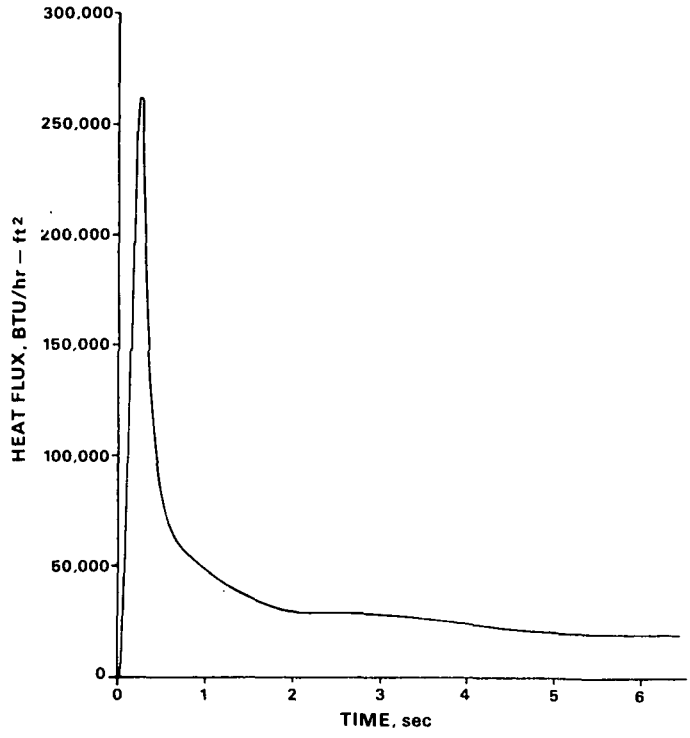

Figure 4. Heat flux into sheet. Same conditions as in Fig. 3.

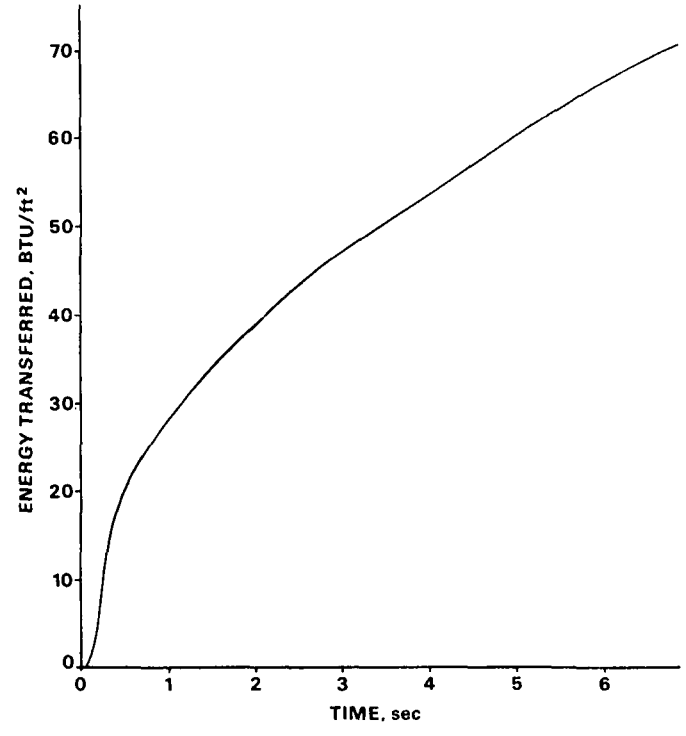

Figure 5. Energy transferred to sheet. Same conditions as Fig. 3.

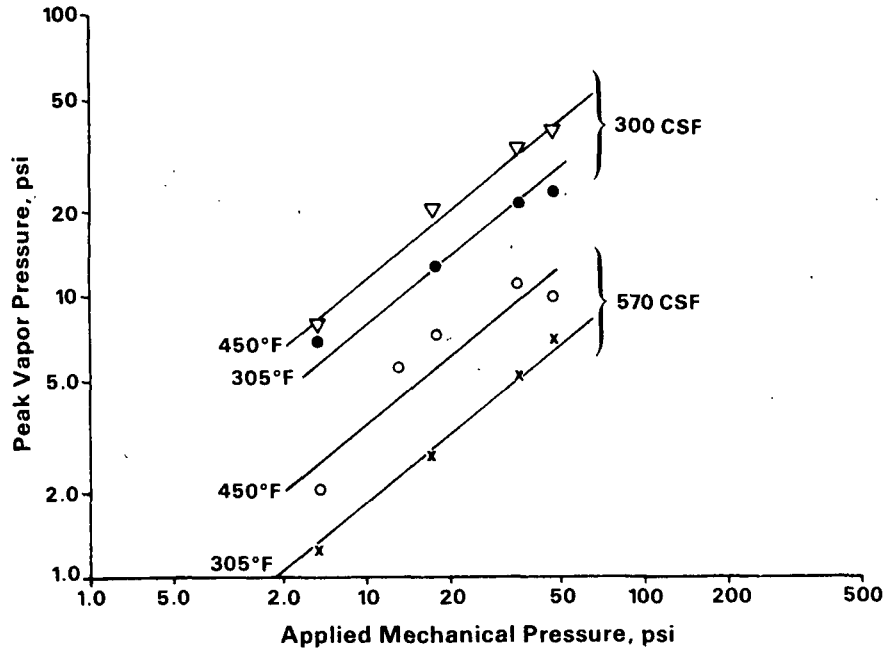

Figure 6. Peak vapor pressure at hot surface for unbleached softwood kraft handsheets, 205 g/m^2, 60% initial moisture content.

The energy transfer curve in Fig. 5 is the time integral of the heat flux from Fig. 4. The level attained near the end of the drying process (at about six seconds) is essentially that expected for a case where all water removal occurs by evaporation. It will be interesting to see whether the measured thermal energy transfer decreases when conditions typical of impulse drying are employed. This would signify the occurrence of liquid-phase dewatering.

WATER REMOVAL AND ENERGY EFFECTIVENESS IN IMPULSE DRYING

Previously reported impulse drying data from the heated roll apparatus were obtained using surface temperatures below 600°F. Recently, some additional water removal data have been obtained for 100 g/m^2 unbleached softwood kraft handsheets at 570 CSF, using temperatures in the 600-800°F range. These new data have been incorporated, along with previous data, into contour maps that facilitate the consideration of temperature-nip residence time tradeoffs. These maps are presented in Fig. 7 and 8, for two values of <u>average</u> nip mechanical

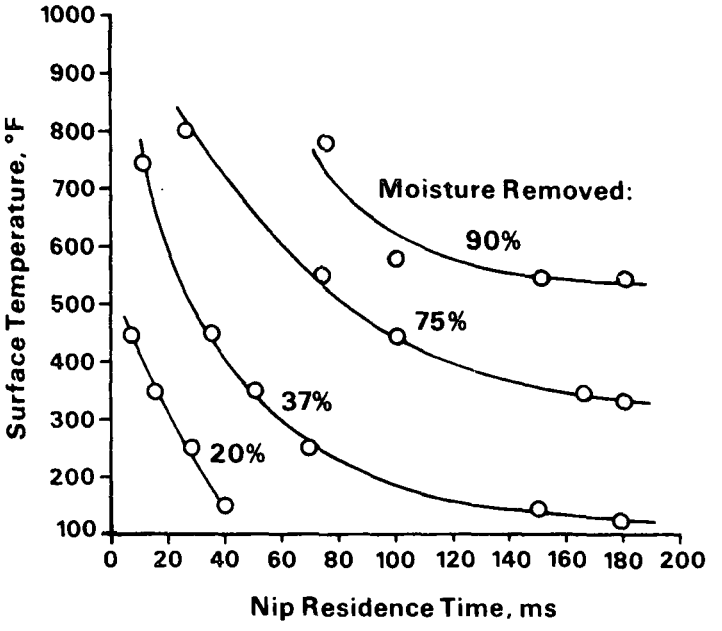

Figure 7. Relative moisture removed during impulse drying: 100 g/m^2 unbleached softwood kraft handsheets (570 CSF) at 58% initial moisture content, with 880 psi average mechanical pressure applied.

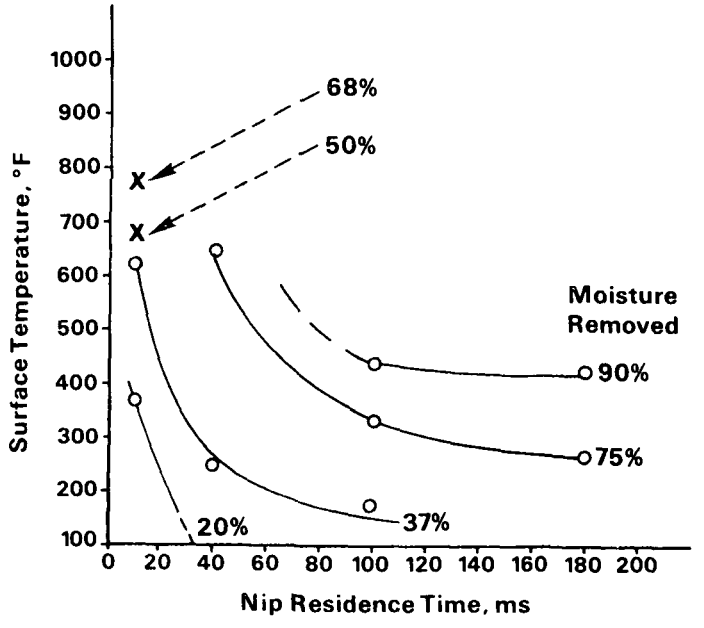

Figure 8. Relative moisture removed during impulse drying: same sheet specifications as in Fig. 7, with 1760 psi average mechanical pressure applied.

pressure (also an important influence on water removal). It is seen that, for very high pressure and temperature, the majority of the water in the sheet can be removed in times similar to those prevailing in an extended nip.

The "drying rates" at the extreme conditions are very large. For example, the point in Fig. 8 corresponding to 75% water removed at 40 ms (at 650°F, 1760 psi) is equivalent to a drying rate of approximately 3800 lb/hr ft^2. It is certainly likely that an appreciable component of the water removal must be in the liquid phase, for such high rates to occur. If this is true, the thermal energy needed for drying would be reduced accordingly. In order to determine the approximate amounts of liquid dewatering which do occur, some tests have been performed to determine the amount of loss of a tracer (sodium fluorescein), considered to be transported from the sheet by liquid water. Results of these tests are given in Fig. 9 and 10 for nip residence times of 10 and 25 ms, respectively. The data are very encouraging in that they show a tendency for both the absolute amount and the proportion of liquid removed to increase as the total water removal increases (i.e., at higher temperature and longer time). It must be acknowledged that some uncertainties exist in translating the dye loss amounts into water removal figures. Two potential sources of uncertainty (which tend to compensate) are the possibility of nonuniform dye concentration (at the fiber level) in the sheet before testing and dilution of dyed water in the cooler portion of the sheet by condensation. While these possibilities are under investigation, neither is presently thought to be of extreme importance.

It is worth noting that one test condition was explored using 100 g/m^2 handsheets made from once-dried bleached kraft pulp at 720 CSF. At 550°F, 880 psi average pressure and 25-30 ms nip residence time, 80% of the initial moisture (the initial moisture ratio was approximately 1.5) was removed with

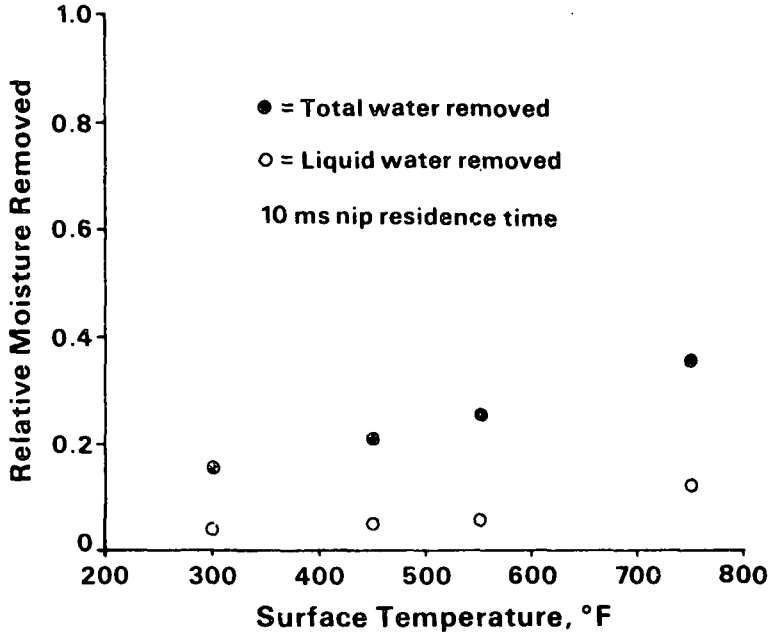

Figure 9. Total relative moisture removed and relative moisture removed as liquid: same sheet specifications as in Fig. 7, with 880 psi average applied mechanical pressure applied and 10 ms nip residence time.

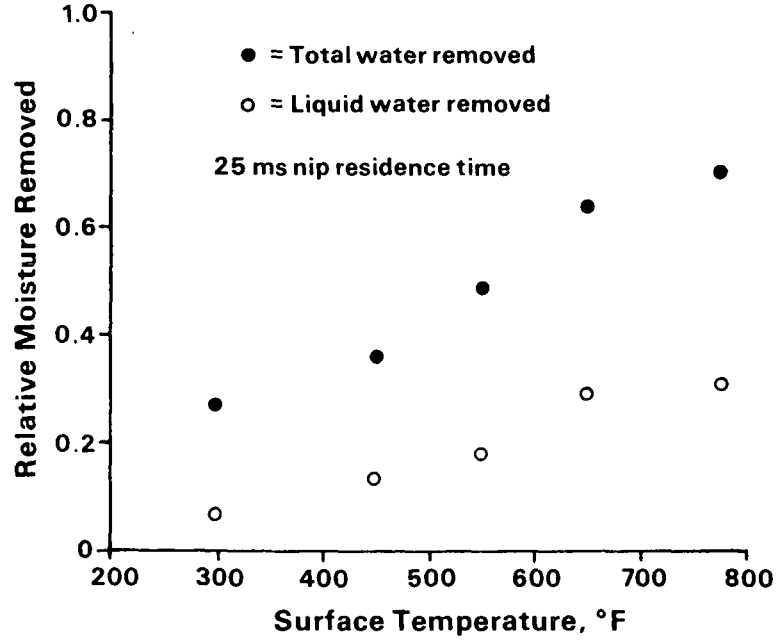

Figure 10. Total relative moisture removed and relative moisture removed as liquid: same conditions as in Fig. 9, except 25 ms nip residence time.

about two-thirds of this occurring in the liquid state! Interestingly, the amount of vapor-phase water removal was about the same as occurred from the sheets upon which Fig. 10 is based, at the same operating condition.

ENGINEERING AND SYSTEM ASPECTS OF IMPULSE DRYING

It is of interest to consider (on a preliminary basis) some of the engineering implications and questions suggested by the water removal maps (for 100 g/m^2 sheets) shown in Fig. 7 and 8. In general, it appears that nip residence times typical of extended nip presses (e.g., 50 ms) would be needed to produce interesting amounts of water removal (e.g., on the order of 75% of the initial moisture present) from these sheets. It is clear, however, that high average nip pressures and high surface temperatures would also be required. For example, according to Fig. 7 and 8, surface temperature/average pressure combinations of about 660°F/880 psi or 540°F/1760 psi would be needed to achieve 75% water removal in a nip residence time of 50 ms.

The high temperature levels indicated for impulse drying suggest that practical alternatives to steam heating will be necessary. Some options that should be considered include: direct heating of the dryer surface with combustion products, indirect heating (e.g., circulating of heated liquids through the shell), and electrical heating. The various options will not only have impacts on the operating cost, but also on the associated equipment size (due to heat flux limitations, etc.).

The relatively severe operating conditions indicated for impulse drying also suggest that mechanical design considerations will play a major role in defining the practical limits of impulse drying, as they do in defining the optimum configuration in Yankee dryers. In particular, the mechanical effects

of high pressures and temperature levels and large temperature gradients in the nip region will require careful analysis. On a different scale, it should be noted that as nip pressure levels and residence times are increased, the structure required for the dryer will become considerably more massive. There is no apparent reason why the economic optimum size will be the same for impulse drying as it is for wet pressing with extended nip technology, but this will need to be explored.

The energy implications of the liquid removal data in Fig. 9 and 10 are very significant. For example, at the maximum water removal conditions shown in Fig. 10 (having a total of 70% of the initial sheet moisture removed, with 30% of the initial moisture removed as liquid), only about 600 Btu/lb fiber would be needed for "drying." In contrast, it is estimated that about 1500 Btu/lb fiber (2½ times that of the impulse dryer case) would be used in a conventional dryer to accomplish the same amount of dewatering. It should be noted that these estimates assume the conventional dryer uses about 50% more energy per unit of evaporation than does the impulse dryer, reflecting the greater losses expected in a conventional system as a result of the much larger size and the indirect heating method.

In contrast to the reduced quantity of energy needed with impulse drying, it should be observed that the quality (value) of the energy required to provide the high temperature levels associated with impulse drying may exceed that used in conventional dryers. It is obvious, therefore, that the overall energy and cost implications of impulse drying will need a much more complete evaluation after more extensive performance data are available.

TECHNICAL EVALUATION OF ADVANCED WATER REMOVAL PROCESSES

Advanced water removal processes such as impulse drying or thermal/vacuum drying may be better suited, technically and economically, for some paper grades than for others. To provide the data needed to more completely characterize the performance of these drying systems and for determining the most attractive applications, bench-scale tests covering a representative range of paper grades, furnishes, and operating conditions will be undertaken. A significantly expanded data base, covering drying rates, energy consumption, paper properties, etc., will be developed in this test program.

Unfortunately, it is impractical to experiment with all combinations of fiber furnish, refining level, basis weight, etc., over a broad range of operating conditions. Therefore, a limited selection of these combinations, representative of certain important paper and board grades, has been tentatively selected for use in evaluating the advanced processes. Based on production figures the grades listed in Table I seem reasonable for this study. A preliminary

TABLE I

CANDIDATE GRADES FOR CHARACTERIZATION TESTS

Paper	Percent of Total U.S. Production[a]	Board	Percent of Total U.S. Production[a]
1. Newsprint	7.7	4. Linerboard	23.1
2. Uncoated printing or writing paper	13.2	5. Corrugating medium	7.3
3. Tissue	7.2	6. Recycled Paperboard	11.6

[a]Combined paper and board production. Overall, grades listed represent about 70% of total U.S. paper and board production.

list of specifications representative of these candidate grades and the paper properties to be evaluated for each are presented in Table II.

A large number of handsheets, dryed over very broad ranges of mechanical pressure, surface temperature and heating time, will be required in this technical evaluation program. Limitations of the existing thermal/vacuum and

TABLE II

PRELIMINARY SPECIFICATIONS AND PAPER PROPERTIES TO BE EVALUATED FOR THE CANDIDATE PAPER AND BOARD GRADES

Grade	Furnish	Basis Weight, lb/ft^2	Pulp Freeness, CSF	Properties to be Evaluated[a]
1. Newsprint	TMP	30/3000	350	Tear, ink penetration, brightness, opacity, smoothness, porosity, pick
2. Uncoated printing/ writing paper	Fully-bleached softwood kraft	50/3000 (?)	300	Same as for newsprint, plus: water resistance, folding endurance
3. Tissue	Fully-bleached softwood kraft	7.5/2880	400?	Water absorption, stiffness, wet strength, porosity, brightness, light-scattering coefficient, bulk
4. Linerboard	~60% yield unbleached softwood kraft	42/1000	600	Burst, STFI compression, smoothness
5. Corrugating medium	NSSC	26/1000	?	Concora, water absorption, STFI compression
6. Recycled paperboard	?	?	?	Stiffness, plybond, STFI compression, (smoothness, ink absorption, pick)

[a]The following properties would be evaluated for all the grades and are not listed: tensile properties, caliper, basis weight, density, ultrasonically-evaluated elastic stiffnesses.

impulse drying devices would make the test program difficult to accomplish. Therefore, a more versatile drying system is being planned, based on the use of a rapid-response hydraulic system. The ideal system would permit a wide range of mechanical pressure levels to be applied to the sheet during drying and allow for various pressure-time profiles to be applied. This would enable simulation of single or multiple nips with a wide range of durations. Use of various "drying heads" would allow thermal/vacuum, impulse or press-drying conditions to be established.

NEAR TERM GOALS

The project goals for the next reporting period are all related to the broader characterization and evaluation of the advanced, high-intensity water removal processes. They are as follows:

1. The versatile drying apparatus needed for the extensive characterization test program will be prepared. This will include design and construction of the drying heads, procurement of the needed hydraulic system elements, and installation of the full system.

2. The broad characterization program will be initiated and pursued. This will involve preparing final specifications for the "grade/furnish/property test" matrix (see Table II) to be considered in the program, obtaining the needed fiber furnishes, conducting base line properties evaluations, performing scoping tests to establish the ranges of drying time and operating conditions of probable interest for each grade, and systematically evaluating the effects of operating conditions on the drying behavior and paper properties.

3. The characterization test results will be utilized in defining and evaluating the engineering aspects of implementation. In particular, the heat input time/surface temperature/mechanical pressure combinations required to achieve relevant dryness and paper properties targets will be used to define appropriate system configurations and heat source alternatives. System and engineering analyses of the alternatives will be initiated in order to guide the selection of the most promising water removal system concepts.

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

Status Report

to the

ENGINEERING PROJECT ADVISORY COMMITTEE

Project 3479

HIGHER-CONSISTENCY PROCESSING

February 10, 1984

PROJECT SUMMARY FORM

DATE: February 8, 1984

PROJECT NO. 3479 - Higher-Consistency Processing

PROJECT LEADER: J. D. Sinkey

IPC GOAL: Reduction of the "necessary minimum" complexity of process steps - screening, cleaning, and forming systems.

OBJECTIVE:

Establish methods and techniques for measuring, changing and controlling the state of fiber flocculation, dispersion and orientation so that such operations as screening, cleaning, and forming can be carried out at higher consistencies which are possible today without adversely affecting the process or the properties of the product. Short term goals: (a) develop techniques for measuring fiber flocculation, dispersion and orientation, and fluidization of the suspension; (b) establish means for achieving relevant states of fiber dispersion and orientation.

CURRENT FISCAL BUDGET: $130,000

SUMMARY OF RESULTS SINCE LAST REPORT:

Following the establishment of new staffing, the orientation of the project was changed from a purely fundamental approach, to emphasize the development of principles useful in practical unit operations. To determine future project direction, a list of potential approaches to higher-consistency forming and separation was assembled, followed by critical assessment with respect to several criteria. For the three most viable concepts, preliminary experiments are presently being designed to establish the most fruitful avenues for further study. Future activity, as yet undefined, will involve the acquisition of both fundamental and applied knowledge of potentially useful higher-consistency processing principles and techniques.

INTRODUCTION

Work on this project was suspended after the May, 1983 resignation of the Project Leader, Dr. Evaristo Bonano. The October, 1983 Status Report discussed work completed just prior to Dr. Bonano's departure. The effort was devoted to quantifying and characterizing changes in floc sizes and their distributions in a converging-diverging channel, and to theoretical analysis of fiber shape and orientation in a slurry under hydrodynamic forces.

The stated objective of the project was to study fundamentals of the mechanics of fiber network disruption in slurries at "higher consistency" (HC). "HC" means higher consistency than conventionally used in a given unit operation. The unit operations of primary interest are forming, screening, and cleaning. Therefore, the consistency range in question is over 1%, and particularly between 2 and 6%. Refining and pumping at "HC," for example, have been considered beyond the scope.

With the recent firming up of project staffing, near-term tasks have been directed to reviewing and reassessing the direction for the research to take. Such a re-evaluation may ensure that our thinking is not restricted to well-established grooves, and that creative approaches are not stifled. Furthermore, it is essential that the work be relevant to industry needs. It is, therefore, desirable to consider:

- what should our ultimate objective be?
- what are the possible approaches to attaining that objective?
- which approaches would be best to pursue, in view of the probability for success, the impact or payback, etc.?

PROJECT PERSPECTIVE

The tendency of fibers to lock together in slurries and form coherent networks inhibits independent movement of fibers, shives, and contaminant particles in the unit operations of interest. The flocculating tendency of fibers has always been overcome by adding sufficient water to minimize fiber-fiber interactions. Unfortunately, this approach leads to tremendous capital and operating costs for the transport and removal of large amounts of water. It has long been a dream to be able to carry out these unit operations at higher consistencies, thereby drastically reducing equipment and system sizes, pumping costs, and the need for large water-removal equipment. There clearly seems to be a need for developing and implementing new principles of handling HC stock.

Concepts which promise efficient HC fiber separation abound in the patent literature. For example, usable feed consistencies claimed for screens vary from the 2-5% range (1), up to 12% for an apparatus claimed to be useful for both screening and cleaning applications (2). These examples, like many others, are based on the use of rapidly moving bumps, ribs, bars, dimples, etc., to induce a fluidizing turbulence to the stock in the vicinity of the screening slots or holes. Drawbacks often encountered include a considerable dewatering of rejects (so that the accepted stock may not be such high consistency after all), and high energy requirements. Wahren (3) has noted that the power dissipation per unit volume required for fluidization of fiber networks increases with consistency to the 5.3 power: from 0.06 hp/gal at 1% consistency, to 20 hp/gal at 3%, to 11,000 hp/gal at 10%. Obviously then, to practically achieve really good turbulent fluidization at HC levels will require restricting power application to very small volumes.

A different method proposed for separating the components of slurries for HC screening, cleaning, and fractionating involves the use of a spray atomizer (4, 5). This method combines the effects of centrifugal force and shear on an atomizing wheel with dispersive effects as the suspension leaves the wheel edge. The optimum consistency range is stated as 3-6%. The failure of this concept to attain wide commercialization is apparently related to energy requirements, scale-up factors, and separation efficiencies.

In the area of HC forming, possibly the most significant work of recent years is that of Grundstrom et al. (6, 7). Their development of a HC (3-6%) former has been shown to be industrially feasible. However, in contrast to conventionally-formed sheets, these HC-formed sheets have a felted structure, due to considerable z-direction fiber orientation. This improves pressing and drying rates, and imparts improved compressive strength and Scott bond values. The reduction in MD and CD strength, however, is a serious drawback for most grades. Hence, the challenge of HC forming of sheets, with properties like those of conventionally-formed paper, remains. Control of fiber orientation is a major aspect of this challenge.

Our substantial knowledge of the behavior of HC fiber slurries and network structures, as applied to the unit operations of interest here, was summarized by Wahren (3). In the last ten years, and especially the last five years, little progress has been reported in developing new principles, or applying established principles, to acquiring practical technology for HC processing. Given the widely acknowledged need for such technology, perhaps we are facing a dearth of good ideas.

In light of these and other considerations, the orientation of this project was changed from a purely fundamental approach to an emphasis on the definition of principles which may be useful in practical technology development. The restatement of the project objective reflects that change. It speaks to what knowledge and methods need to be developed, on a basic level, in order to attain the program goal of reducing the complexity of screening, cleaning, and forming systems. Compared to previous effort, the work envisioned here is less fundamental, more applied in nature. It is directed to the development of useful methods, and not merely to the acquisition of a body of knowledge. Nevertheless, it is clear that new understanding of the response of fibrous networks to various forces (hydrodynamic and mechanical) is needed. We need a better understanding of various principles of fiber network dispersion in order to develop techniques of controlling particle orientation and motion. Clearly the project will have both fundamental and applied aspects.

SHORT-TERM TASKS

The following list of six tasks was designed to start us on what will hopefully be a fruitful path toward the objective.

Task 1. Conceptually identify and categorize potential methods of HC forming and separation.

Task 2. Critically assess these candidate approaches or methods with respect to the following criteria:

- odds for favorable result (obviously very subjective with respect to both the definition of "favorable result" and its probability)
- potential payback of favorable result (the benefit of the information, process, or product which could ultimately result)
- facility and cheapness (time, money, and complexity) of a preliminary study of feasibility - the initial risk or investment needed to do a first-cut assessment

- the uniqueness and aptness of a potential IPC contribution, WRT what others are doing and have done and the "fit" with the Institute research mission

Task 3. Assign priorities based on the above, to decide the preferred order of investigating the alternatives.

Task 4. Devise and carry out experiments to assess the feasibility of the most promising candidate approaches or techniques.

Task 5. Based on results, update the assessment in Task 2, and reprioritize the most promising avenues to study.

Task 6. Proceed with more in-depth studies.

CLASSIFICATION OF CONCEPTUAL METHODS (TASK 1)

This task involved a bit of brainstorming activity, addressing the question, "what possible approaches might there be to HC processing?", reserving judgment on the merit of the ideas for Task 2. The result of this blue-sky thinking, of course, was a list of concepts, some of which had been tried in the past with varying degrees of success, and some of which represented quite new approaches. Although the entire list would not be worth reproducing here, some discussion of the categorization of the ideas may be worthwhile.

The potential HC methods were divided into forming methods, and separation methods. The former included the requirement of control of fiber orientation, with strength and other properties at least as good as conventionally-formed sheets. Screening, cleaning, and fractionation type operations were listed together in the latter, since many of the concepts in that category could be applied to separation of dirt, shives, or fibers from the bulk slurry. The final list contained four distinct possible approaches to separation. Forming methods included two main categories, and five second-level classifications, for a total of about ten distinct potential HC forming concepts. Totally far-out ideas were not necessarily listed, but every attempt was made to include any

concept which might have a chance of being developed into a useful approach, given existing technology.

CRITICAL ASSESSMENT OF CANDIDATE CONCEPTS (TASK 2)

As mentioned above, the purpose of this evaluation was to determine which concepts or approaches we ought to investigate first, according to the four criteria. In considering methods of forming vs. methods of separation, it is obvious that these are different areas of study rather than alternative approaches to the same end. The question is still the same, though: How much effort should we spend on each, according to what priority? The payback for success in a screening/cleaning "breakthrough" would be more immediate than with forming - the latter is not as easily retrofitted for new technology, or easily tried out in the field. A new screening concept, e.g., can be installed as a small-scale parallel unit in the field fairly easily, in contrast to a new forming unit. In addition, HC separation offers the potential of eliminating more capital equipment than HC forming (dewatering devices, tanks, pumps, etc.). On the other hand, we seem to have more ideas to explore with forming than with separation, a factor which may improve the odds for success with forming.

With these and other factors in mind, each concept was evaluated according to the four criteria. On a scale of 0 to 100, the odds for success of the various concepts were judged to be in the range of 5 to 40%. On a scale of 0 to 10, the potential benefit of a favorable result ranged from 3 to 9, with the separation methods ranking higher than most of the forming methods, for the reasons cited above. The facility and cheapness of a preliminary study varied only from 3 to 6, while appropriateness as an IPC project ranged from 2 to 9. Low ratings in the latter category were given to approaches which have been or

are being investigated extensively by others, and to concepts which involve considerable hardware or equipment development without the promise of shedding light on a generally applicable principle. The most appropriate type of project for IPC would seem to be one involving the definition or development of new principles which could be applied and embodied in a variety of ways by others, in developing needed technology.

Overall ratings, obtained by equal weighting of the four criteria, ranged from 30 to 66%. In the following section is a brief discussion of the four top-rated concepts, two of which are forming and two of which are separation methods. Their assessment is summarized in Table I.

TABLE I

ASSESSMENT OF TOP FOUR HC APPROACHES

Concept or Approach	Odds for Success, %	Potential Benefit	Facility and Cheapness of Prelim. Study	Aptness for IPC	Overall Rating, %
Separation by shear in liquid phase	25	9	6	9	66
Separation of sprayed particles	30	8	6	7	60
Elongational flow-extrusion forming	10	8	6	7	55
Forming fabric in turbulent zone	25	6	5	8	54

THE MOST VIABLE APPROACHES

SEPARATION BY SHEAR IN LIQUID PHASE

This separation technique is based on the tendency of large particles to move away from a region of intense shear in a liquid, while small particles may remain in the shear region (8). This effect may play an important part in separation in the spray atomizer (4, 5). In embodiments envisioned here, shear would be induced by a rapidly moving roll surface, and controlled by a gap with a stationary element, or by another roll which forms a nip with the first.

The potential exists that such a technique could allow separation of dirt, shives, etc., in one operation, without air entrainment. The application is not without potential problems, however. The nature of pulp separation commonly observed in a shear field (pipe wall, e.g.) is separation of fines in water vs. fibers away from the shear zone. It is uncertain whether useful separation of dirt, shives, etc., could be effected in this way. It would probably require very precise physical definition of the line of separation. The means by which the fractions would be removed from the separating zone would have to be developed.

SEPARATION OF SPRAYED PARTICLES

This is a different embodiment of the atomizer wheel concept discussed above (4, 5), possibly using different forces. The idea of using spray techniques rather than hydrodynamic or mechanical turbulence to disrupt fibrous networks seems to be worth further pursuit. Particles of various size and density would be separated in spray and move relative to one another, under the influence of surface tension, gravity, drag forces, centrifugal force, etc. One

embodiment would involve creating the spray from the surface of a rapidly moving roll, using much the same experimental setup as in the previous all-liquid approach.

The potential benefit of this approach is similar to the previous one, except for the air entrainment associated with the spray. A possible way to address this would be to carry out the spraying in a steam environment. With both these concepts, success will depend on minimizing the volume to which energy is applied, and applying the various forces in such a way as to enhance the desired separations.

ELONGATIONAL FLOW-EXTRUSION FORMING

This approach to achieving desirable fiber alignment with HC forming is probably the most logical "next step," given exisiting technology, even though the odds for success seem slim. It essentially involves using existing HC forming technology to generate a "fluidizing" level of turbulence (6, 7), followed by immediate application of elongational flow forces to induce fiber alignment, before the turbulence decays and the slurry reaches the forming fabric. Bonano (9) has suggested that elongational flow, and not simple shear, is necessary for fiber alignment to take place in a flowing fluid. Conceptually, a logical way to achieve this would simply involve passing intensely turbulent HC stock through a converging channel, discharging through a very small opening at the forming fabric. This may be likened to the long-held dream of extruding a sheet of paper directly from a HC suspension. Perhaps the thickness of the discharge opening (spinneret?) could be much less than a fiber length, to minimize z-direction orientation. In addition, it may be possible to superimpose a sonic or ultrasonic vibration in the converging channel to prolong and promote fiber dispersion.

If successful and energy-efficient, such a technique would be very attractive by virtue of its simplicity, compared with other concepts which may have many moving parts, etc. However, several problems may be envisioned. A major one concerns the time element: the rapid decay of turbulence compared with the time required to reorient the fibers in the elongational flow field. Another concerns the energy required to generate the intense turbulence needed, plus force stock through the small channel. There may also be a problem with a randomizing disruption of the fibers in the jet as it leaves the opening. The imposition of microscale vibrations could be beneficial, but it is difficult to imagine how this could physically be accomplished with sufficient amplitude, without applying high amounts of energy to vibrate large surface areas. Any superimposed vibration applied to maintain fiber dispersion would have to be confined to a microscale in order to be practical energy-wise.

FORMING FABRIC MOVING THROUGH TURBULENT ZONE

This concept would involve either a hydrodynamic or mechanical turbulence generating means (rough-surfaced, rapidly moving roll, e.g.), with a forming fabric passing through the turbulent zone, presumably near the stock-air interface. Fiber orientation would be achieved by fibers being caught in the forming fabric and dragged, during initial dewatering. Controlled upward suction would be applied at a very early stage of forming.

A successful implementation of this concept would probably involve a more complex system, with more critical operating conditions, compared with an elongational flow former. The means of controlling the turbulence and the fiber orientation are unknown.

FUTURE WORK

The previous section summarized the efforts in connection with Task 3: the assignment of priorities for investigating the alternatives, based on assessment per the listed criteria (Table I). Present and near-term future activity will be concerned with Task 4: the design and completion of preliminary experiments to better evaluate the viability of the top-rated approaches.

The two separation concepts will be studied using substantially the same apparatus. It will consist of a roll, capable of high surface speeds and capable of being fitted with various surfaces, coming in close, variable proximity to another roll or a stationary separating blade. Means will be provided for supplying pulp to this turbulent zone, and for removing "rejected" material. For the liquid-phase concept, the downstream "accepts" zone will be kept submerged, with suitable doctoring and sealing means provided. For the spray technique, the accepts zone will be provided with adjustable collectors for receiving the atomized material.

For preliminary study of the elongational flow extrusion former, a conventional HC forming apparatus will be constructed, feeding into adjustable transparent converging channels. The extent of dispersion and fiber orientation will be assessed as a function of the geometry of the converging channel, and other variables. Preliminary studies of the fourth priority concept will only be undertaken after some results are obtained with the top three.

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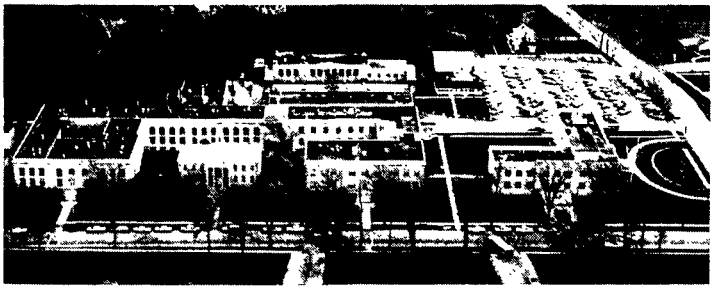


THE INSTITUTE OF PAPER CHEMISTRY, APPLETON, WISCONSIN

SLIDE MATERIAL

for the

ENGINEERING PROJECT ADVISORY COMMITTEE

March 21-22, 1984

The Institute of Paper Chemistry
Appleton, Wisconsin

TABLE OF CONTENTS

		Page
Project 3309:	Fundamentals of Corrosion Control in Paper Mills	1
Project 3556:	Fundamentals of Kraft Liquor Corrosivity	22
Project 3384:	Refining of Chemical Pulps for Improved Properties . . .	32
Project 3480:	Wet Pressing Fundamentals	42
Project 3470:	Fundamentals of Drying	53
Project 3479:	Higher-Consistency Processing	65

Project 3309

FUNDAMENTALS OF CORROSION CONTROL IN PAPER MILLS

David F. Bowers

FUNDAMENTALS OF CORROSION CONTROL IN PAPER MILLS

OBJECTIVE

TO IMPROVE THE LIFE OF PAPER MACHINE SUCTION ROLLS BY CORROSION AND CORROSION FATIGUE STUDIES AND LABORATORY INVESTIGATIONS OF FAILURE PREVENTATIVE MEASURES

PLAN

FY83-84: REVIEW AND EVALUATE CORROSION RESISTANCE

FY84-85: CORROSION/CORROSION FATIGUE STUDIES

FUNDAMENTALS OF CORROSION CONTROL IN PAPER MILLS

PROJECT REVIEW

- TEST MATERIALS - SUCTION ROLL ALLOYS
- CHARACTERIZATION OF MACHINED SURFACES
- CORROSION TEST RESULTS
- INVESTIGATION OF FATIGUE DETERRENTS - SHOT PEENING/BURNISHING
- PLANS - CORROSION AND CORROSION FATIGUE STUDIES

PROJECT RELATED STUDIES

- CORROSION TEST PROGRAMS
  - BELOIT/SANDUSKY: TEST SPOOLS W/SCC SPECIMENS
  - BELOIT: LABORATORY ELECTROCHEMICAL AND EXPOSURE TESTS
  - PAPER COMPANIES
- CORROSION FATIGUE TESTING
  - INDUSTRIAL MATERIALS RESEARCH INSTITUTE OF CANADA
  - RADIAN CORPORATION
  - BATTELLE/SANDUSKY
  - TAPPI
  - ROLL SUPPLIERS
- ROLL FAILURE STUDIES
  - CONSULTANTS
  - SUPPLIERS
  - INSURANCE COMPANIES

SUCTION ROLL ALLOYS

- BRONZE
  - 1N (85 Cu 5 Su 5 An 5 Pb) - CENTRIFUGAL CAST
  - GC (Cu Sn 5 Zu Pb) - CONTINUOUS CAST
  - GC (Cu Al 9, 5 Ni) - CONTINUOUS CAST
- AUSTENITIC
  - CF-3M (SIMILAR TO AISI316L) - CENTRIFUGAL CAST
  - PM-3-1809N (SIMILAR TO CF-8M) - FORGED
  - ALLOY 63 (22% Cr, 9% Ni, 2.75% Mo) - CENTRIFUGAL CAST
  - PM-3-1811MN-.04 (SIMILAR TO CF-3M) - FORGED
- MARTENSITIC
  - CA15 - CENTRIFUGAL CAST
  - PM-4-1300 - FORGED
  - PM-4-1300M (1.5-2.5 Mo) - FORGED

SUCTION ROLL ALLOYS

- DUPLEX
  - ALLOY 75 (26% Cr, 6% Ni) - CENTRIFUGAL CAST
  - KCR171 (SIMILAR TO A75) - CENTRIFUGAL CAST
  - PM-2-2309 (22/26% Cr, 9% Ni) - FORGED
  - PM-2-2505 (24/30% Cr, 5% Ni) - FORGED
  - 3RE60 (18% Cr, 5% Ni, 3% Mo) - ROLLED/WELDED
- OTHERS
  - VK-A 682 (18% Cr, 5% Ni, 3% Cu, 1% W, 2% Mo) - CENTRIFUGAL CAST
  - 223 FAL (SIMILAR TO 3RE60) - ROLLED/WELDED
  - VK-A378

SURFACE FINISH - SUCTION HOLE (RMS)*

ALLOY	DRILLING METHOD TWIST	TWIST/REAM	GUN
BRONZE	- -	40	- -
CA-15	200/300	40/70**	- -
ALLOY 75	200/500	40/70	- -
CF-3M	200/500	40/70**	- -
KCR171 AND OTHER STAINLESS	- -	- -	25/40

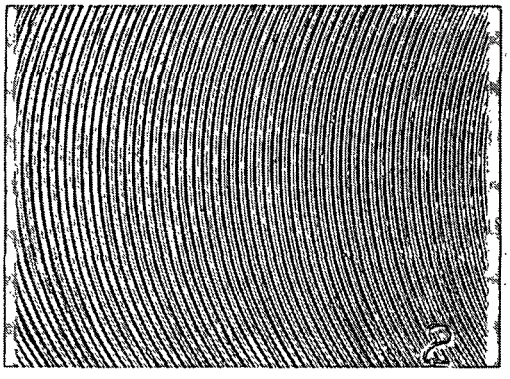
* ESTIMATED, NOT MEASURED ROUTINELY

** SELDOM USED

SURFACE FINISH - SHELL ID (RMS)

ALL ALLOYS	DOMINION*	125
	BLACK CLAWSON*	63
	SANDUSKY	50

* REPORTED BY KUBOTA, AMERICA



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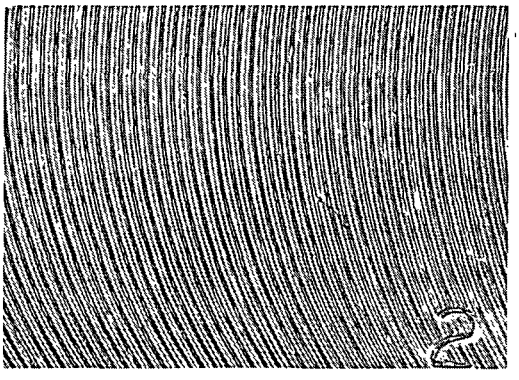

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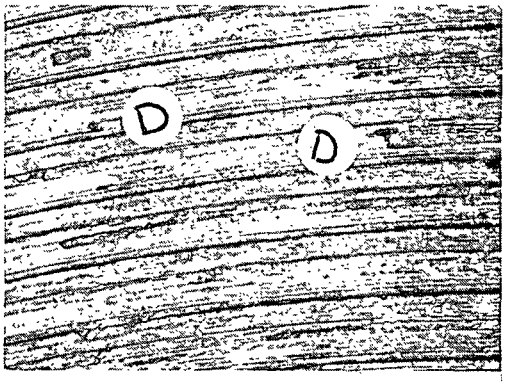

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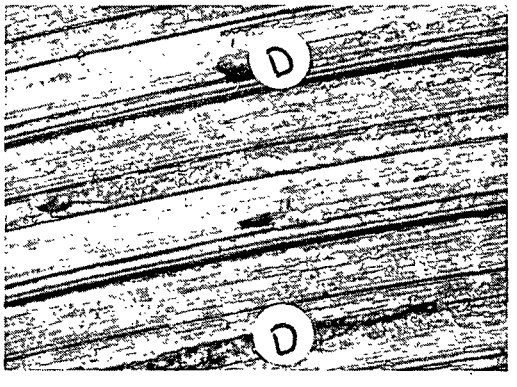
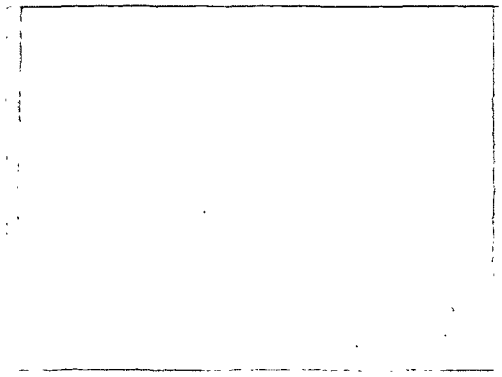


37X

Characterization of specimen surface for CF-3M (250 RMS), as machined prior to test. Note surface defects marked "D".



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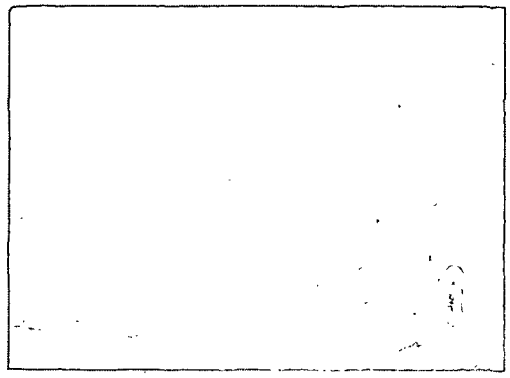

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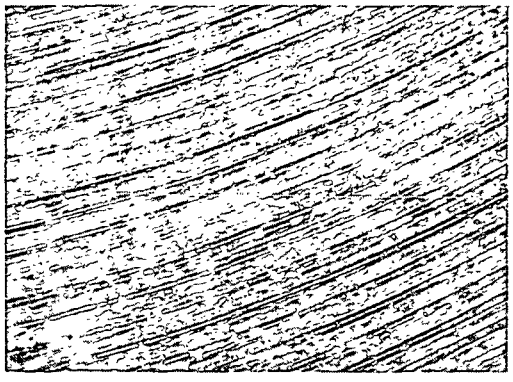

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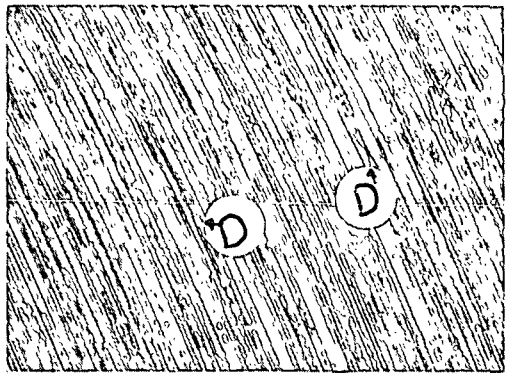


37X

Surface characterization of specimens, A75 (50 RMS), as machined prior to test. Note defects at "D".

CORROSION TEST PROGRAM

ALLOYS TESTED: 1N BRONZE, CA-15, A-75, KCR171, CF-3M

TEST ENVIRONMENTS

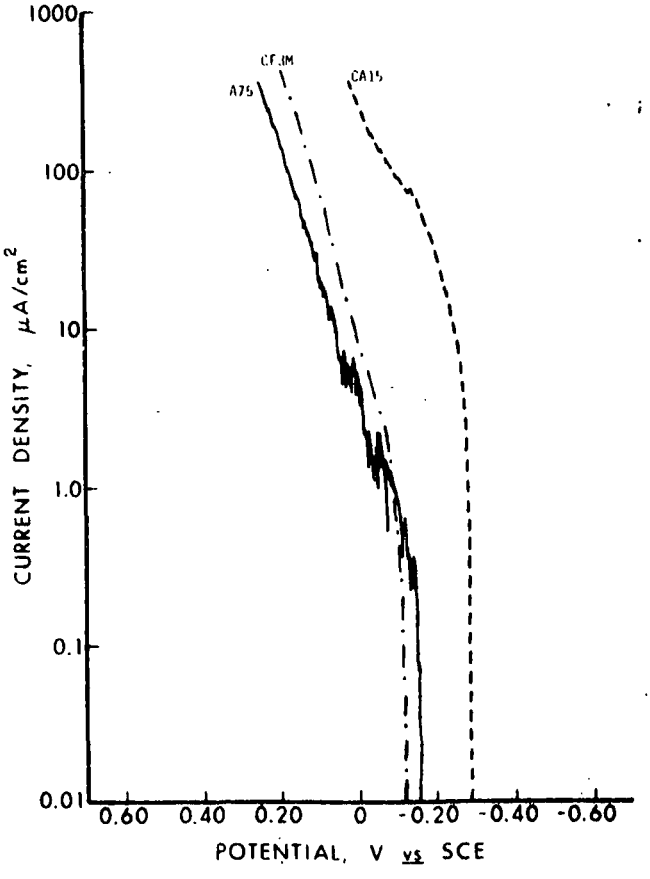
TYPE	pH	Cl(PPM)	SO_4(PPM)	THIOSULFATE (PPM)
TAPPI I	3.5	100	1000	- -
TAPPI II	3.5	1000	1000	- -
WWI	4.1	200	500	50
WWII	4.1	200	500	- -

CORROSION TEST PROGRAM

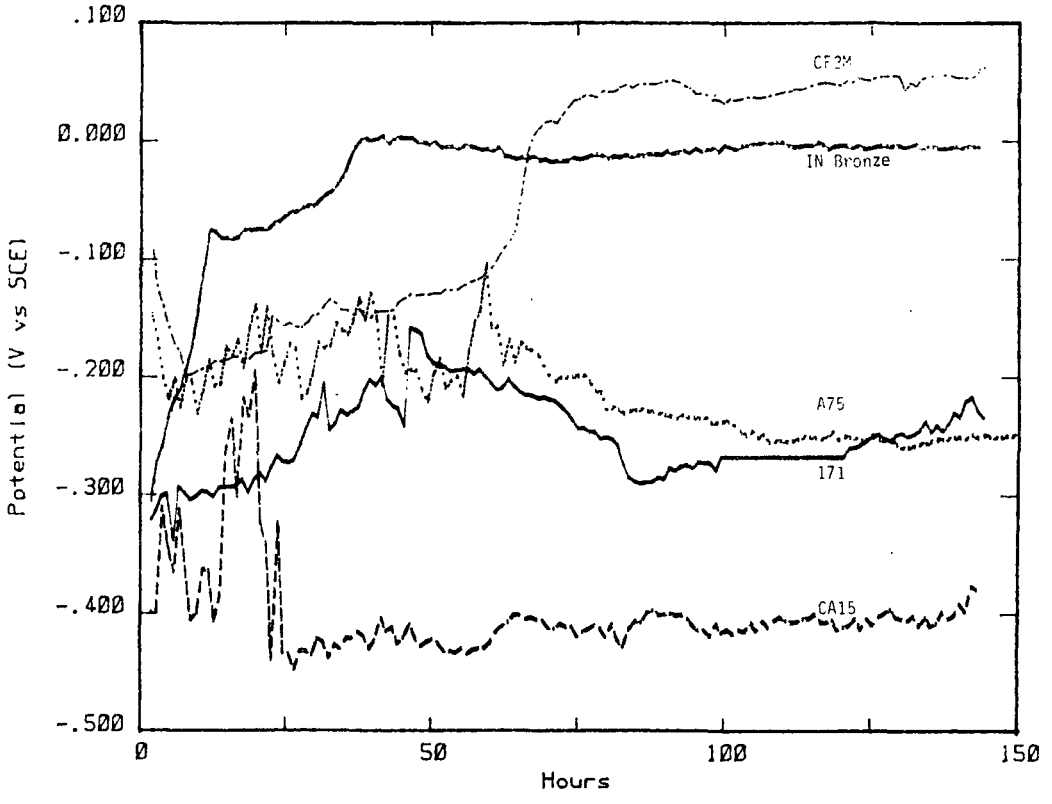
TEST METHODS:

- EXPOSURE (POTENTIAL DECAY) WT.LOSS
  - STATIC
  - FLOWING (7.5 f.p.s.)
- POLARIZATION
  - ANODIC SCAN: STAINLESS STEELS
  - LINEAR POLARIZATION: BRONZE

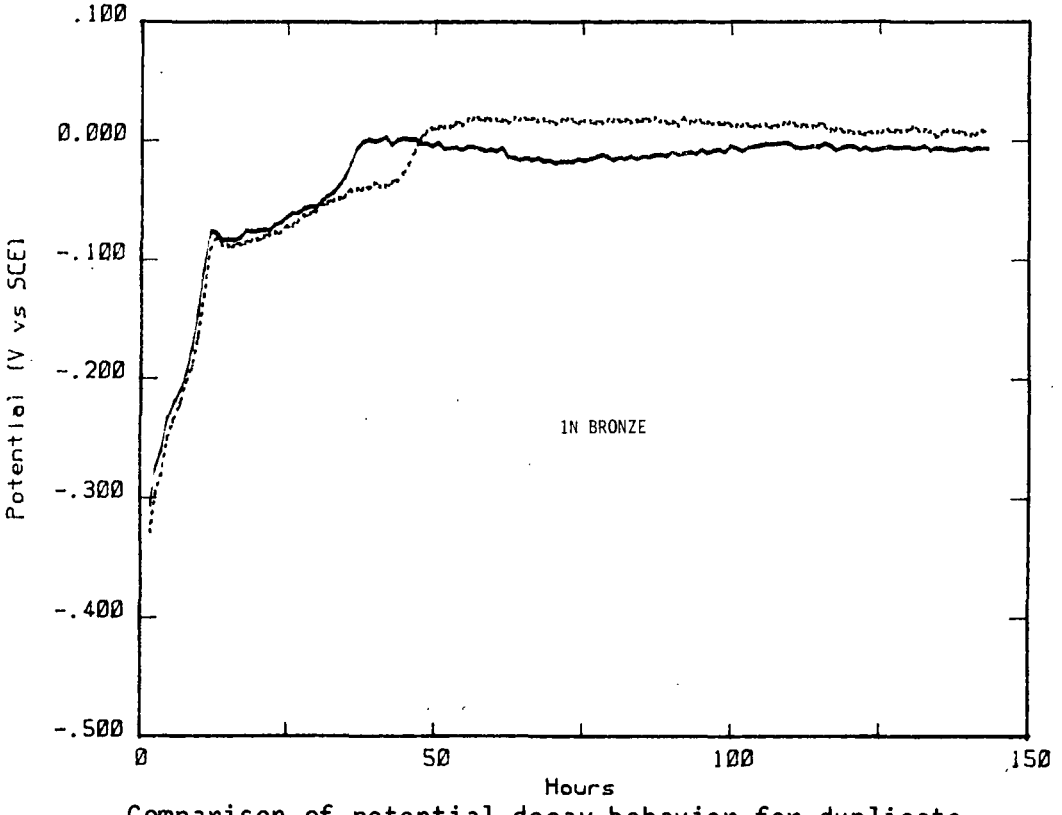
TEST TEMPERATURE: 55°C - ALL TESTS



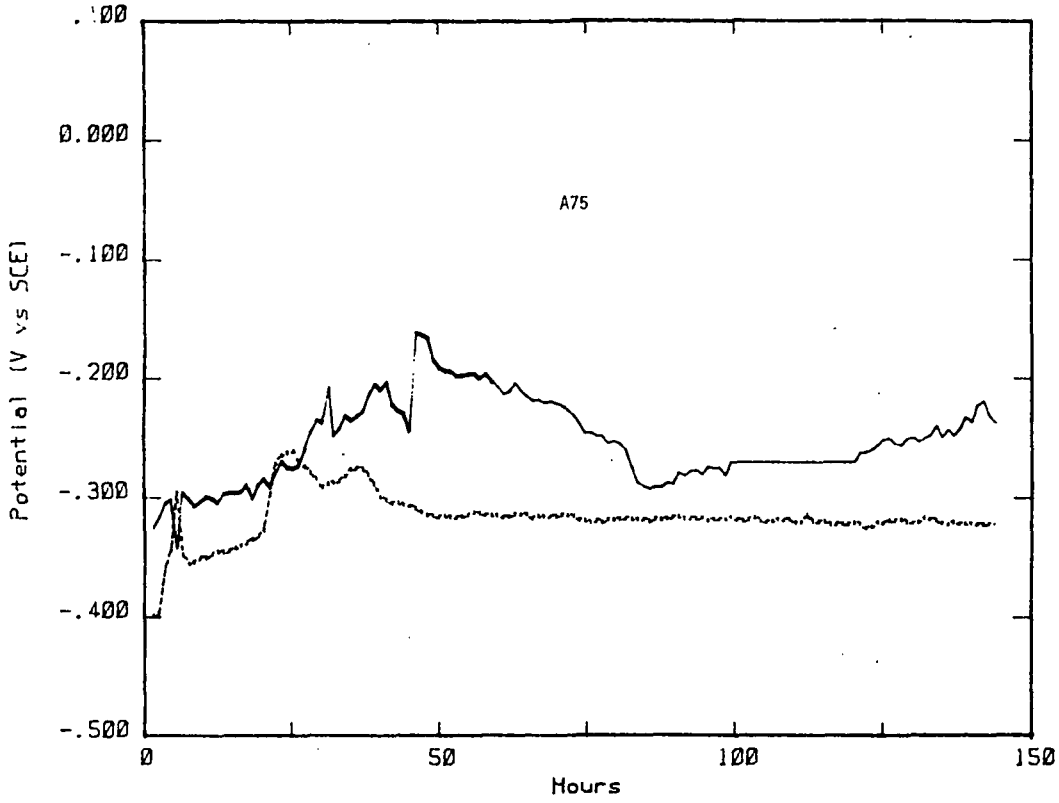
Anodic polarization behavior of suction roll alloys in TAPPI II water, 55°C, 0.6 v/hr.



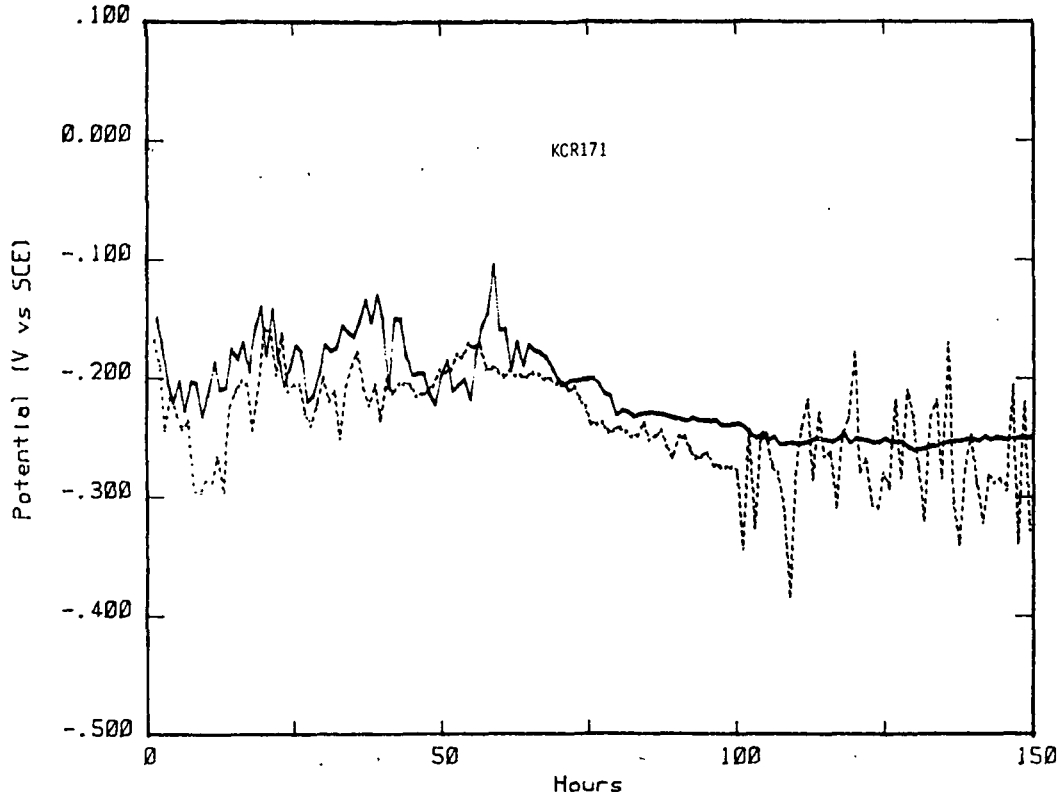
Potential decay behavior of suction roll alloys in WWI water, 55°C.



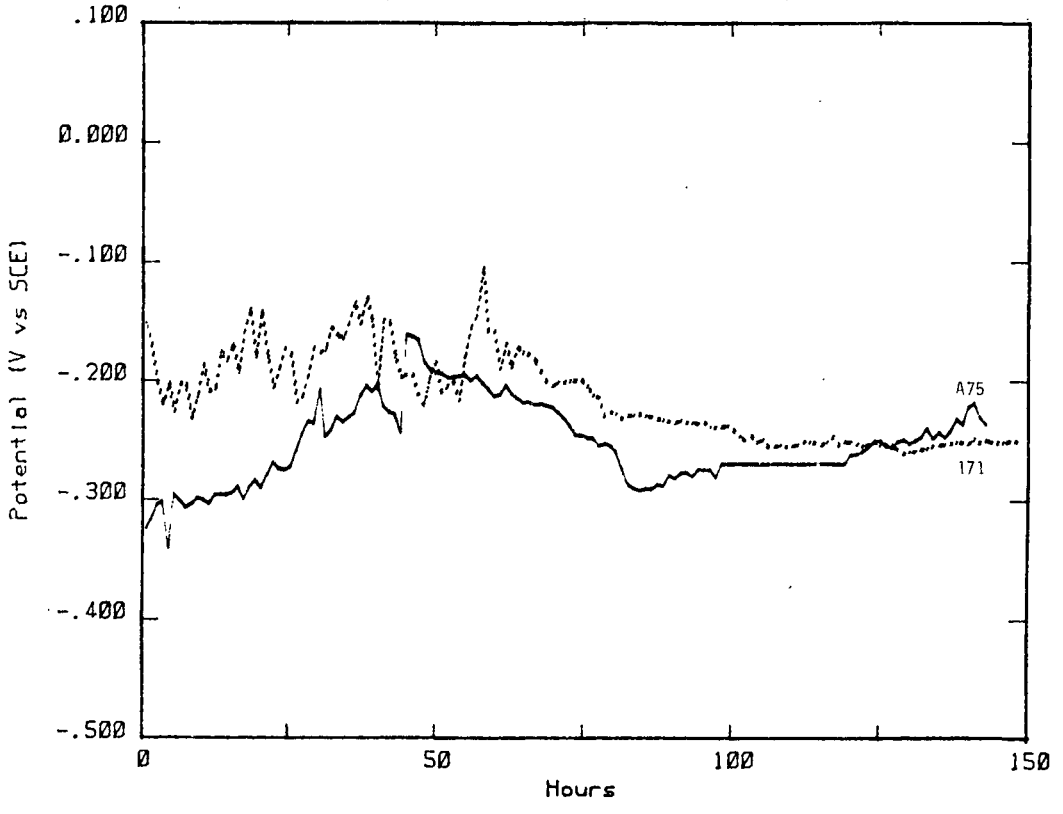
Comparison of potential decay behavior for duplicate specimens of 1N bronze in WWI water, 55°C.



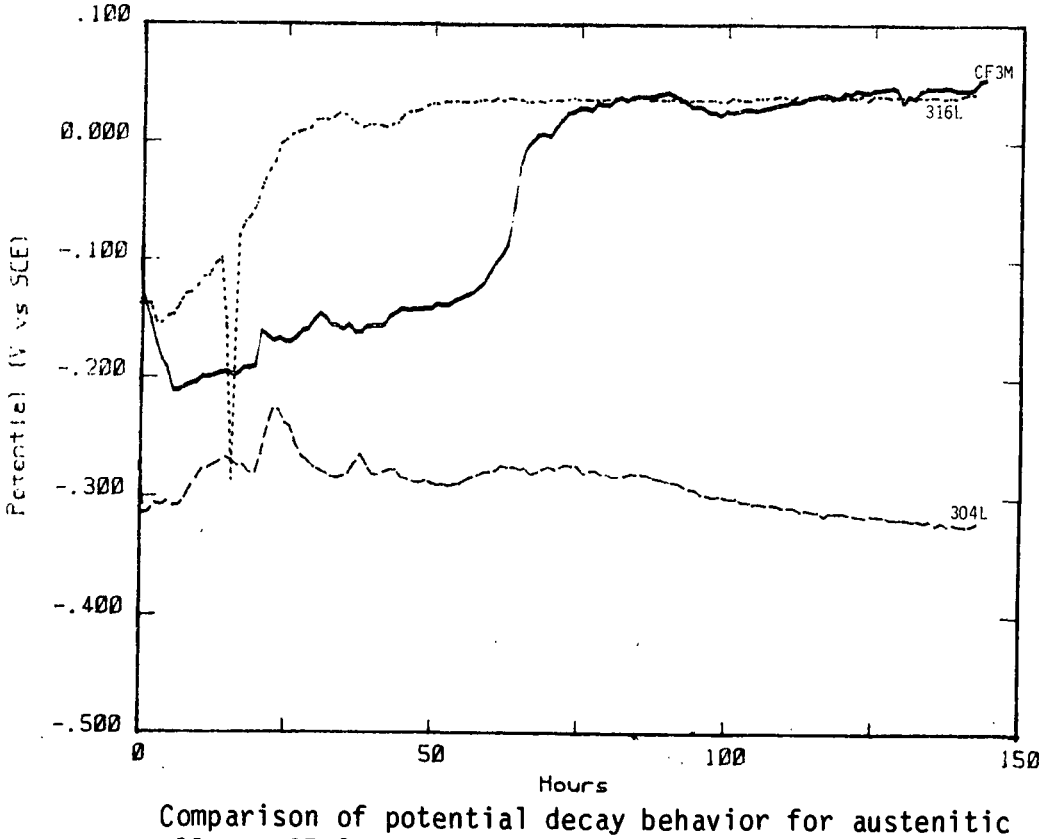
Comparison of potential decay behavior for duplicate specimens of A75 in WWI water, 55°C.



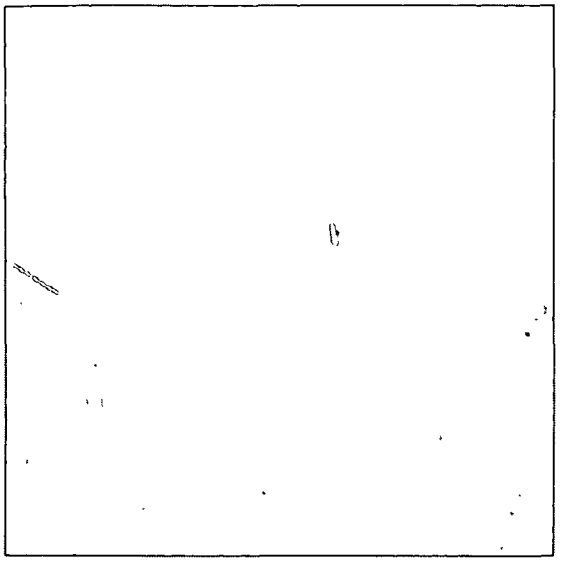
Comparison of potential decay behavior for duplicate specimens of KCR171 in WWI water, 55°C.



Comparison of potential decay behavior for duplex alloys A75 and KCR171 in WWI water at 55°C.



Comparison of potential decay behavior for austenitic alloys, CF-3M, AISI316L and 304L in WWI water at 55°C.



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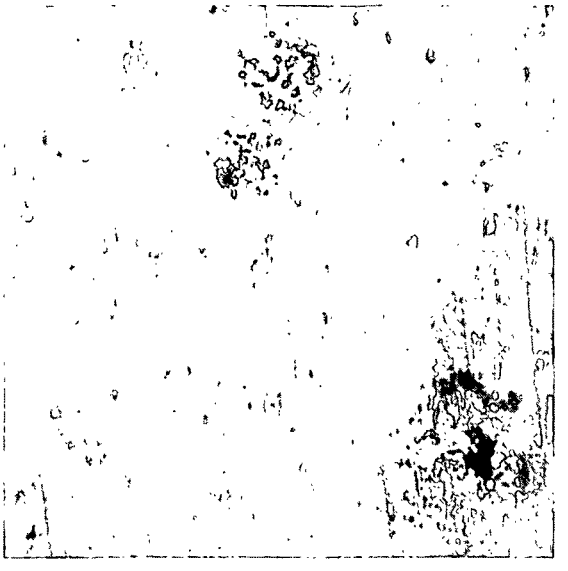
CA-15



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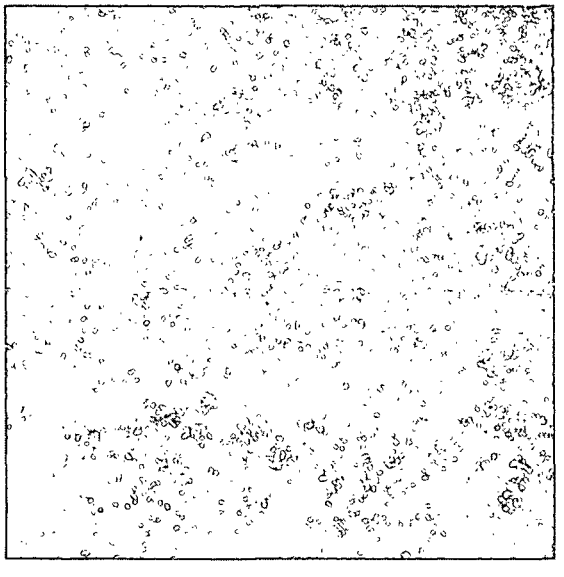

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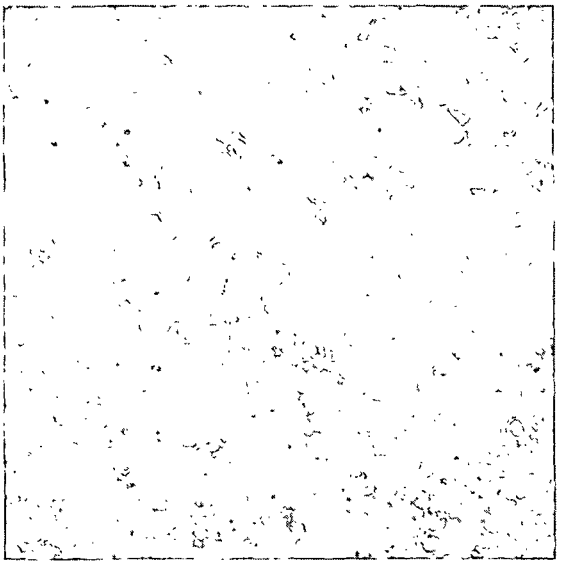
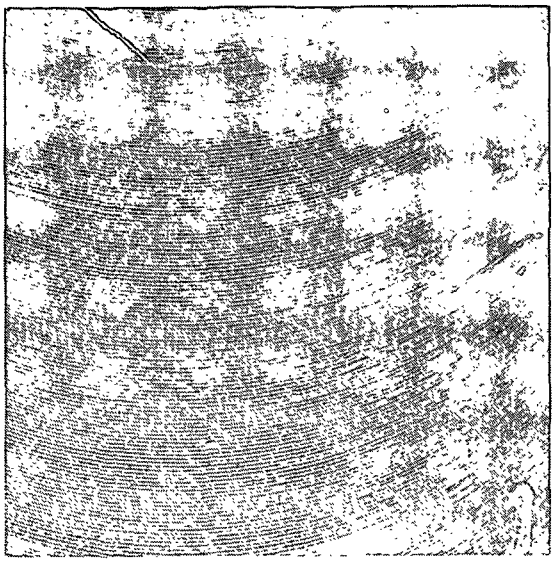
IN Bronze

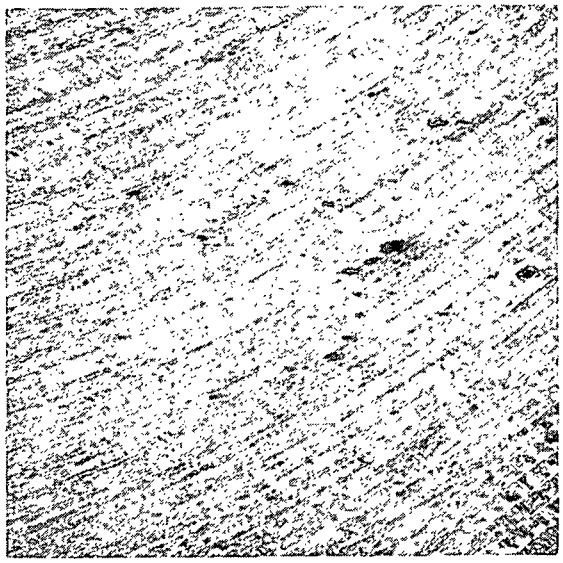


13X

Appearance of CA-15 and bronze coupons after exposure (static system) to TAPPI II water. Note crevice corrosion on CA-15 coupon on top.



A-75



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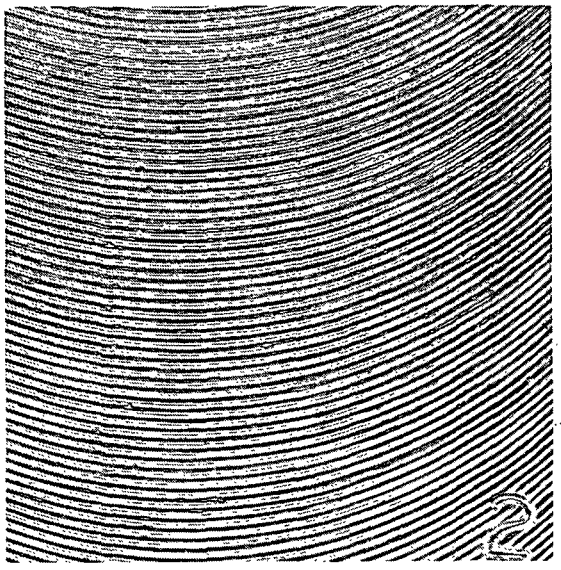
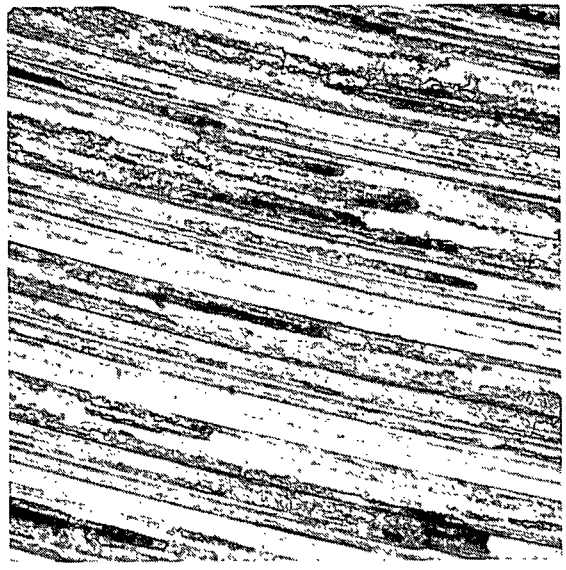


CF-3M



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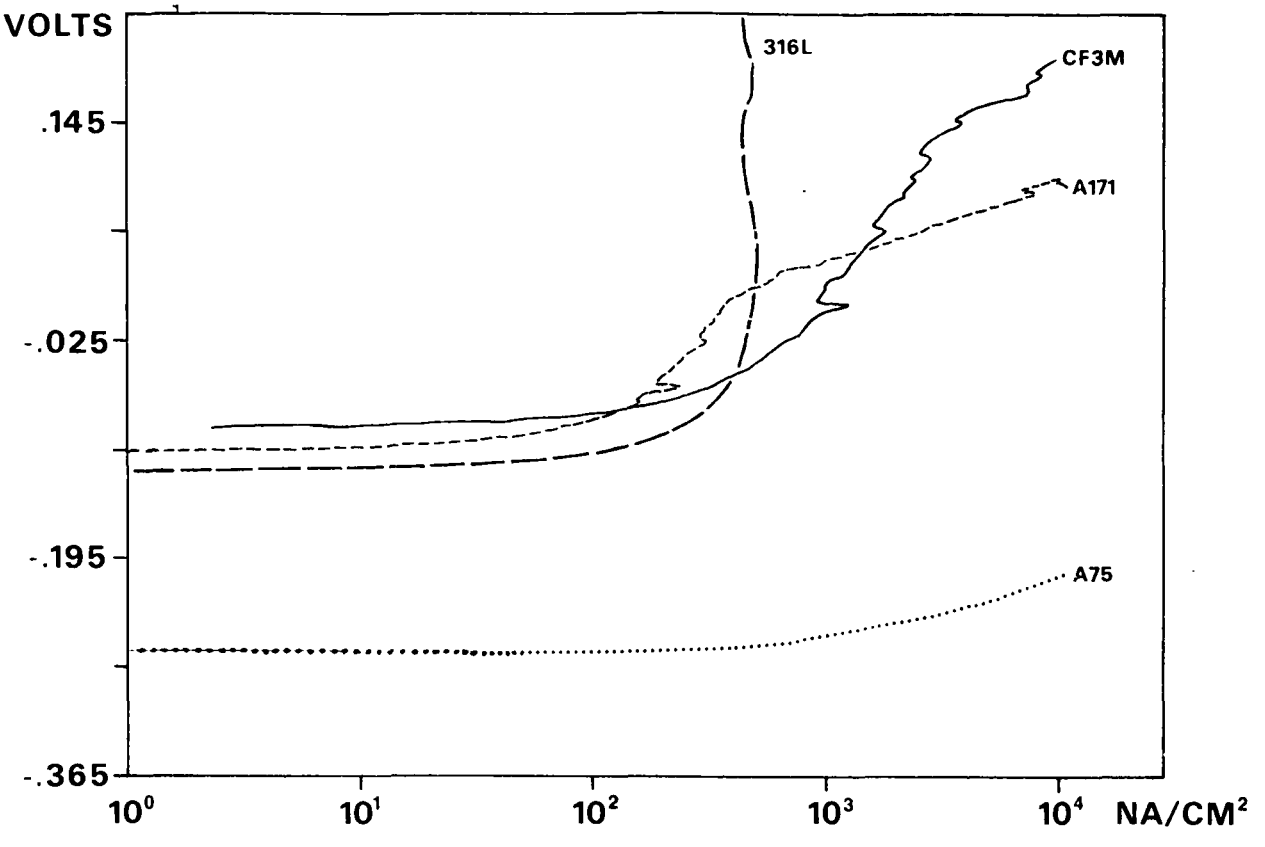
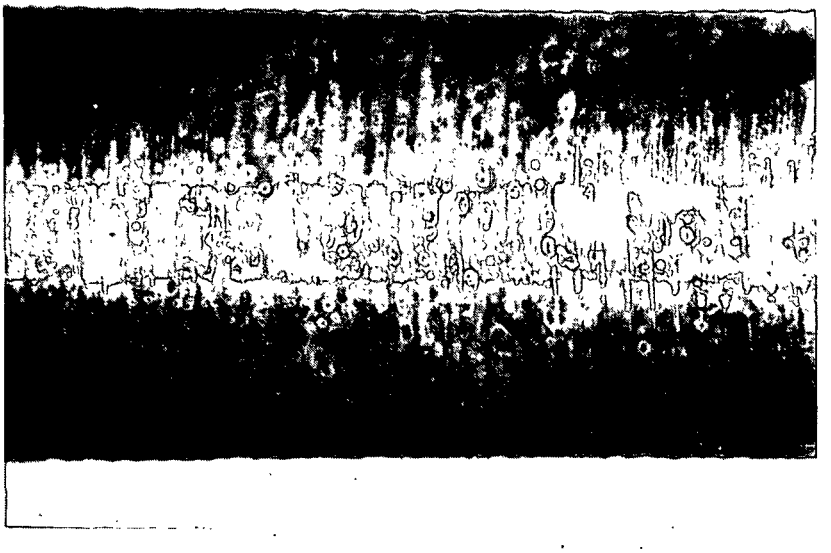
37X

Appearance of A75 and CF3M coupons after exposure to flowing TAPPI II water. Note elongation and widening of former defect sites by corrosion.



Anodic polarization behavior of suction roll alloys in WWI water, 0.3 v/hr., 55°C.



Appearance of CA-15 test specimen after anodic polarization test in WWI water, 0.3 v/hr., 55°C. (9X)

CONCLUSIONS

1. THE CORROSION RESISTANCE OF SUCTION ROLL ALLOYS DEPENDS ON THE QUALITY OF MACHINED SURFACES

2. SURFACE FINISH OF SUCTION ROLLS, PARTICULARLY HOLE I.D., IS NOT WELL CHARACTERIZED: IT IS ONLY ESTIMATED IN RMS

3. CORROSION WAS RAPID AND PROGRESSIVE AT SURFACE DEFECTS ON MACHINED COUPONS, REGARDLESS OF ALLOY, IN ALL TEST ENVIRONMENTS

CONCLUSIONS

4. CORROSION RESISTANCE FOLLOWED POSITIONS OF NOBILITY, i.e., CA-15 < A171 $\leq$ A75 < BRONZE < CF-3M

5. METHODS TO PRODUCE FATIGUE RESISTANT SURFACES, i.e., SHOT PEENING AND BURNISHING, WERE DEMONSTRATED FROM THE STANDPOINT OF TECHNIQUE AND PRACTICE(S) REQUIRED FOR SUCTION ROLLS

CREVICE CORROSION TESTS

(1) ELECTROCHEMICAL - DETERMINE PITTING/PROTECTION POTENTIAL, VIA., POTENTIOSTATIC CURRENT DECAY

(2) CRITICAL CREVICE CORROSION TEMPERATURE

- FERRIC CHLORIDE IMMERSION METHOD
- SANDVIK (ELECTROCHEMICAL METHOD, USING ANDERSON WASHER)

(3) APPLIED POTENTIAL

- O RING
- DEPOSIT
- ANDERSON WASHER

(4) EXPOSURE, LONG TERM - BIOLOGICAL

- INHERENT ("GROW AT WILL" W/DEPOSIT)
- INDUCED (INNOCULATED IN DEPOSIT)

SUCTION ROLL ALLOYS

- CENTRIFUGALLY CAST
  - 1N BRONZE
  - A-63
  - CF-3M
  - A-75
  - KCR171
  - KCR271
  - VKA378
  - VKA682
- CONTINUOUSLY CAST
  - GC (Cu Sn 5 Zn Pb)
  - GC (Cu Al 9, 5 Ni)
- FORGED
  - PM-3-1811MN-.04
  - PM-3-1809N
  - PM-2-2309
  - PM-2-2505
  - PM-4-1300
  - PM-4-1300M
- ROLLED/WELDED
  - 3RE60
  - 223 FAL

SUCTION ROLL ALLOYS

(1) 1N BRONZE
(2) GC (Cu Sn 5 Zu Pb)
(3) GC (Cu Al 9, 5 Ni)
(4) CA-15
(5) PM-4-1300
(6) PM-4-1300M
(7) ALLOY 63
(8) PM-3-1809N
(9) PM-3-1811 MN-.04
(10) CF-3M
(11) PM-2-2309
(12) ALLOY 75
(13) PM-2-2505
(14) KCR 171
(15) KCR 271
(16) VKA 378
(17) VKA 682
(18) 3RE60
(19) 223 FAL
(20) X6

SELECTION OF SUCTION ROLL ALLOYS

FOR FUTURE STUDY

CENTRIFUGALLY CAST		FORGED
ALLOY 63	ALLOY 75	PM-4-1300
CA 15	IN BRONZE	PM-2-2505
CF3M		

CONTINUOUSLY CAST	ROLLED/WELDED(?)
GC (Cu Sn 5 Zu Pb)	3RE60*

* PROMISED, NOT RECEIVED

SELECTION OF SUCTION ROLL ALLOYS FOR FUTURE STUDY

OTHERS AS ALTERNATES OR BY CONTRACT

ALUMINIUM BRONZE [GC(Cu Al 9, 5Ni)]	
PM-3-1811MN-.04	VKA682*
PM-2-2309	VKA378
	X6

AVAILABLE

PM-4-1300M	KCR271
PM-3-1809N	223 FAL

* PROMISED, NOT RECEIVED

FUTURE WORK

SHORT RANGE:

(1) RE-TEST CURRENT CAST ALLOYS WITH "DEFECT-FREE" SURFACES IN WWI WHITE WATER

(2) CORROSION STUDY OF PEENED COUPONS IN WWI WATER

(3) TEST FORGED AND CONTINUOUS CAST ALLOYS TO COMPARE WITH (1) ABOVE

(4) CHARACTERIZE SURFACES PRODUCED BY TWIST AND GUN DRILLING: PERFORM SELECTIVE CORROSION TESTS ON ALLOY BLOCKS - AS DRILLED, DRILLED AND SHOT PEENED, DRILLED W/DEPOSITS

FUTURE WORK

SHORT RANGE:

(5) PERFORM APPROPRIATE TESTS ON ALL ALLOYS FOR CREVICE CORROSION RESISTANCE

(6) FURTHER INVESTIGATION OF SHOT PEENING:

  (a) CORROSION FATIGUE (ROTATING BAR) TESTS ON PEENED AND UNPEENED SPECIMENS: SELECTIVE, ONE STRESS LEVEL, 600 RPM, ONE ALLOY PER FAMILY

  (b) APPRAISE COST EFFECTIVENESS

(7) LITERATURE REVIEW

(8) SURVEY IPC MEMBER COMPANIES TO OBTAIN CURRENT PERFORMANCE OF SUCTION ROLLS

FUTURE WORK

LONG RANGE:

(1) COMPLETE THE EVALUATION OF CORROSION RESISTANCE OF SUCTION ROLL ALLOYS

- CURRENT TEST PROGRAM
- INTERGRANULAR CORROSION TESTS ON A-63, CF-3M, PM-3-1809N (1811MN-.04), PM-2-2505, PM-2-2309
- SELECTIVE LEACHING TEST ON 1N BRONZE AND ALUMINUM BRONZE

FUTURE WORK

LONG RANGE:

(2) FATIGUE CRACK PROPAGATION STUDIES TO ESTABLISH RESISTANCE OF ALLOYS TO FATIGUE AT LOW FREQUENCY (10Hz) IN APPROPRIATE WHITE WATER ENVIRONMENTS

- PREDICTION OF ROLL LIFE
  - MEASURE THRESHOLD STRESS INTENSITY AND CRACK GROWTH RATE
  - CORRELATE MEASUREMENTS WITH ROLL DESIGN PARAMETERS: OPERATING LOAD, RESIDUAL STRESS, AND STRESS CONCENTRATION FACTORS
- MECHANISTIC STUDY OF CORROSION FATIGUE CRACK GROWTH
  - PROCESSES ACTIVE AT THE CRACK TIP, e.g., ELECTROCHEMICAL MASS TRANSPORT KINETICS, SURFACE FIBER PROPERTIES

FUTURE WORK

LONG RANGE:

(3) PURSUE DETERRENTS TO CORROSION FATIGUE CRACK PROPAGATION, e.g., NEW ALLOYS, INHIBITORS, ELECTROCHEMICAL PROTECTION

(4) CONTINUE COMMUNICATION WITH OTHER RESEARCH ORGANIZATIONS

Project 3556

FUNDAMENTALS OF KRAFT LIQUOR CORROSIVITY

Ronald A. Yeske

FUNDAMENTALS OF KRAFT LIQUOR CORROSIVITY

PROJECT 3556

OBJECTIVE

USE ELECTROCHEMICAL METHODS TO UNDERSTAND CORROSION PROCESSES IN KRAFT LIQUORS

- DETECTION
- COST-EFFECTIVE CONTROL

FUNDAMENTALS OF KRAFT LIQUOR CORROSIVITY

PROJECT 3556

WHITE LIQUOR CORROSIVITY

DETECT PERIODS OF HIGH CORROSIVITY	IDENTIFY CAUSES	IDENTIFY REMEDIES	PROBLEM SOLVED
* REFERENCE ELECTRODE DEVELOPMENT	* LIQUOR COMPOSITION EFFECTS	ANODIC PROTECTION (FKBG)	
* LINEAR POLARIZATION METHOD SIMULATION	—> LIQUOR VELOCITY EFFECTS	PROCESS CHEMISTRY CONTROL	
—> ELECTRICAL RESISTANCE METHOD SIMULATION	—> LIQUOR LEVEL EFFECTS		
—> LINEAR POLARIZATION FIELD TESTING			
—> ELECTRICAL RESISTANCE FIELD TESTING			

* DONE
—> 1984-85

FUNDAMENTALS OF KRAFT LIQUOR CORROSIVITY

PROJECT 3556

CONTINUOUS DIGESTER CRACKING

—> LIQUOR COMPOSITION EFFECTS ON CRACKING

IN-SITU ELECTROCHEMICAL TESTING TO DETERMINE CAUSES

—> 1984-85

FUNDAMENTALS OF KRAFT LIQUOR CORROSIVITY

PROJECT 3556

KEY RESULTS

- SILVER/SILVER SULFIDE REFERENCE ELECTRODE
- VERIFICATION OF LINEAR POLARIZATION FOR FOR CORROSION MONITORING
- RESOLUTION OF COMPLICATIONS DUE TO LIQUOR OXIDATION
- PRELIMINARY VERIFICATION OF ELECTRICAL RESISTANCE METHOD FOR CORROSION MONITORING
- IDENTIFICATION OF THIOSULFATES, POLYSULFIDES AS CORROSION ACCELERANTS

CAN THE SILVER/SILVER-SULFIDE ELECTRODE
BE USED AS A REFERENCE ELECTRODE?

ADVANTAGES

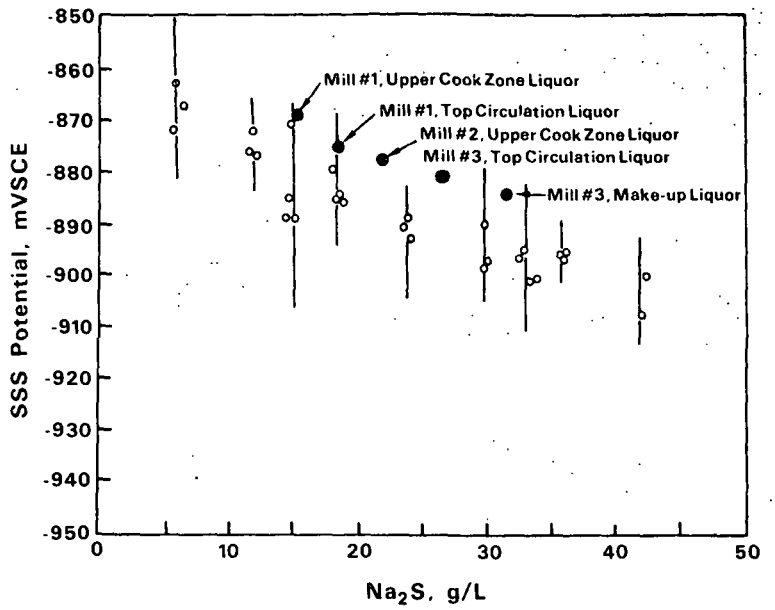
- SIMPLE TO USE (MAINTENANCE-FREE)
- SIMPLE TO INSTALL
- DURABLE
- DIRECTLY IMMERSIBLE
- COMPATIBLE WITH EXISTING PROBES

TABLE I

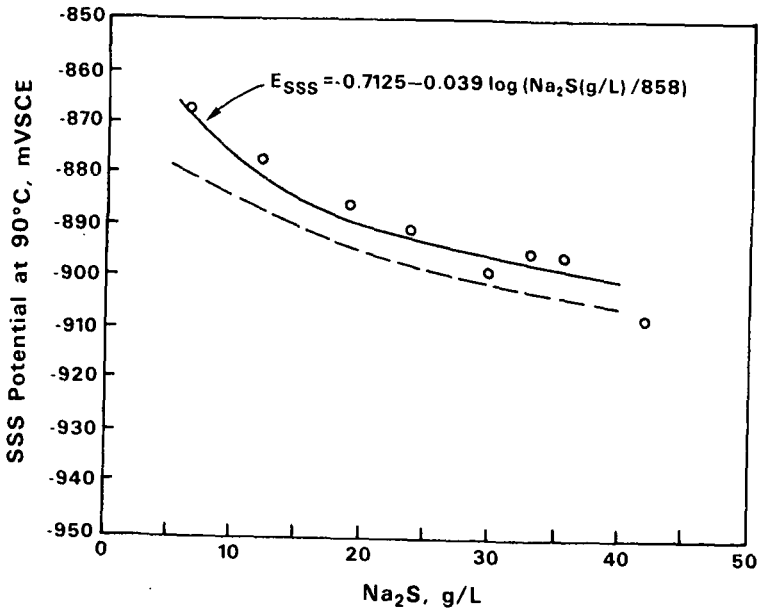
COMPARISON OF INORGANIC COMPOSITIONS

Mill #	Liquor Extraction Site	NaOH	Na_2S	Na_2CO_3
1	Upper Cooking Zone	22	13	29
1	Top Circulation Line	58	17	25
2	Upper Cooking Zone	14	21	17
3	Top Circulation Line	73	26	22
3	Make-Up Line	59	29	22

Composition of actual liquors used in SSS electrode studies.



Effect of organic species on the SSS reference potential at 90°C.



Empirical equation for the SSS reference potential at 90°C.

LINEAR POLARIZATION

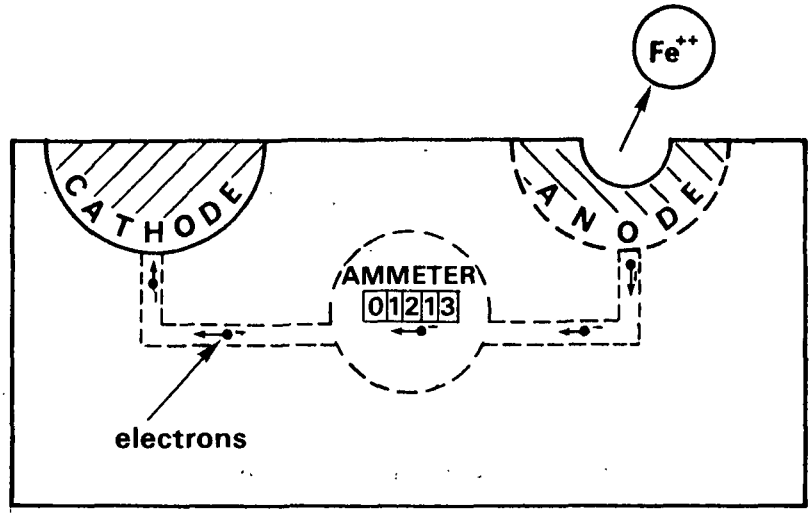
APPROACH

1. Impose a small voltage on a corroding electrode, ΔE
2. Measure the resulting current, ΔI
3. Calculate corrosion current density

$$i_{corr} = \frac{1}{(2.3)} \cdot \frac{\beta_a \beta_c}{\beta_a + \beta_c} \cdot \frac{\Delta I}{\Delta E}$$

4. Calculate corrosion rate

$$CR = \frac{i_{corr} \cdot (\text{mol. wt.})}{(\text{Faraday's constant})(\text{density})(\text{oxidation \#})}$$



An Imaginary Ammeter to Measure the Corrosion Current, i_{corr}

TABLE II

COMPARISON OF CORROSION RATES BY WEIGHT LOSS AND LINEAR POLARIZATION

Liquor (g/L) NaOH	Na_2S	Ave. Corrosion Rate (wt.loss - mpy)	Ave. Corrosion Rate+ (LP)	(β^*/Z) (mV)
60	33	4.4	12.4	14.6
80	33	5.9	15.7	16.1
100	33	5.3	16.1	14.3
120	33	5.4	17.5	13.6
140	33	5.0	16.6	13.2
60	20	4.2	11.5	15.8
60	40	4.0	12.1	13.6
140	40	5.0	17.6	12.6
100	15	4.0	12.9	15.0
100	20	4.4	12.6	15.9
100	25	4.9	14.1	15.0
100	30	4.8	15.9	13.4
100	35	4.2	15.0	11.7
100	40	4.4	14.9	12.9
100	45	4.4	13.0	14.6
100	50	4.4	14.0	13.5

+ These linear polarization measurements of corrosion rates are not corrected for the required adjustment in (β^*/Z) in the governing LP equation.

* (β^*/Z) is the Tafel constant term required to bring LP and weight loss results into agreement.

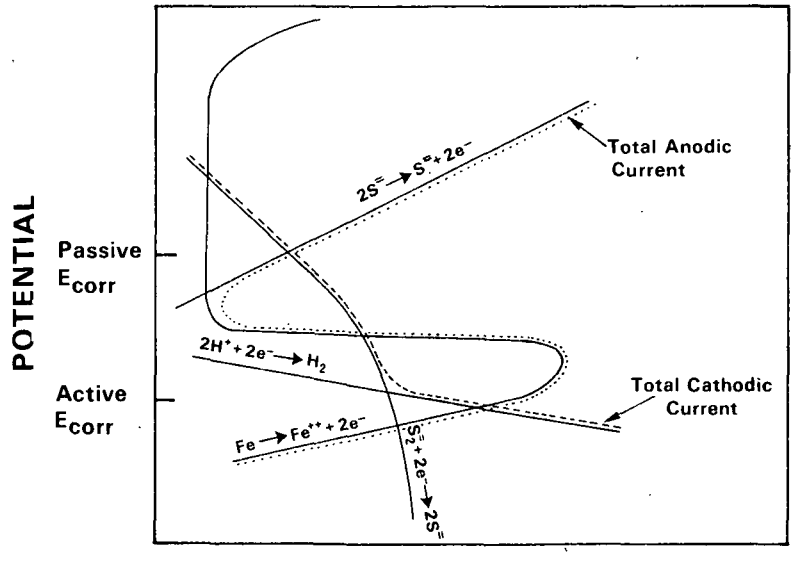
Effect of varying liquor composition on linear polarization results.

EFFECT OF POLYSULFIDE ADDITIONS ON CORROSION RATES FOR CARBON STEEL IN SIMULATED WHITE LIQUORS*

Na_2S_x (as S^o)	Average Corrosion Rate (mpy)		
	Wt. Loss	Cathodic Linear Polarization	Anodic Linear Polarization
0 g/l	6.6	11.0	16.9
0.5	10.3	11.9	15.5
2.5	16.7	19.9	20.1
5.0	5.1	14.3	14.9
10.0	2.5	23.9	24.2

*All liquors contain 100 g/l NaOH and 33 g/l Na_2S at 85°C

Effect of polysulfide concentration on linear polarization results.



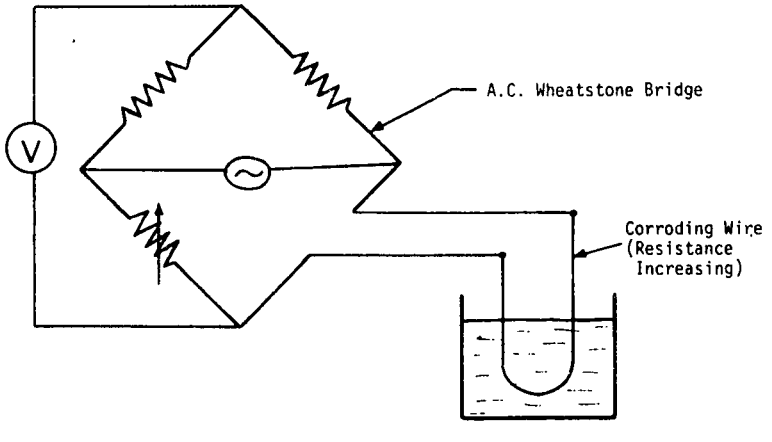
Schematic diagram of the electrochemical response of carbon steel in white liquor, showing liquor oxidation effects.

CONCLUSIONS

- LINEAR POLARIZATION IS GENERALLY RESPONSIVE TO ACTUAL CHANGES IN CORROSION RATE
- ASSUMED TAFEL SLOPES HAVE BEEN TOO HIGH
- MEASURED TAFEL SLOPES GIVE GOOD AGREEMENT WITH WEIGHT LOSS
- SOLUTIONS WITH HIGH POLYSULFIDE ENCOUNTER LIQUOR OXIDATION EFFECTS

ELECTRICAL RESISTANCE METHOD

APPROACH — "Electrical Weight Loss"



$$R = \frac{\rho(\text{Temp.}) \cdot \text{length}}{\text{Area}}$$

Schematic of electrical resistance method for corrosion rate monitoring.

ELECTRICAL RESISTANCE PROBE RESULTS

ADDITIONS	REFERENCE LIQUOR 100 g/L NaOH, 33 g/L Na_2S WEIGHT LOSS (mpy)	ER RESULTS (mpy)
- -	14	13
25 g/L $Na_2S_2O_3$	41	44
10 g/L S° (Na_2S_x)	5	3

Comparison of actual weight loss with ER probe measurements.

VALUE TO THE INDUSTRY

- VERIFICATION AND CALIBRATION OF A USEFUL REFERENCE ELECTRODE
- VALIDATION OF INSTANTANEOUS CORROSION RATE MONITORING IN WHITE LIQUOR
- UNDERSTANDING OF WHICH SPECIES IN WHITE LIQUOR PROMOTE CORROSION
- FUNDAMENTAL UNDERSTANDING OF CORROSION PROCESSES

FUTURE WORK

- SSS POTENTIALS IN HIGH TEMPERATURE LIQUORS
- CORROSION RATE MONITORING REFINEMENT
- SPECIES EFFECTS STUDIES CONTINUED
- CORROSION PRODUCT ASSESSMENT
- EFFECTS OF LIQUOR VELOCITY
- EFFECTS OF ALTERNATE WET-AND-DRY EXPOSURE

Project 3384

REFINING OF CHEMICAL PULPS FOR IMPROVED PROPERTIES

John D. Sinkey

REFINING OF CHEMICAL PULPS FOR IMPROVED PROPERTIES

PROGRAM GOAL:

Develop ways to measure and control manufacturing processes

CONTROL OF AMOUNT OF REFINING

SPECIFIC ENERGY $E_{NET} = \frac{P}{qC}$

CONTROL OF REFINING SEVERITY

SPECIFIC EDGE LOAD $SEL = \frac{P}{\Omega Z^2 L}$

OTHER FACTORS IN REFINING SEVERITY

- CONSISTENCY
- BAR MATERIAL
- BAR HEIGHT
- BAR SHARPNESS
- BAR ANGLE
- FIBER CHARACTERISTICS

ENERGY PER IMPACT

LEIDER AND NISSAN

$$E = \frac{P(M/l_f\ d_f)}{2C\Omega Z^3 L}$$

PROBLEM STATEMENT:

WE HAVE NO GOOD MEASURE OF, OR CONTROL OVER, THE TYPE OR INTENSITY OF REFINING

SO WHAT?

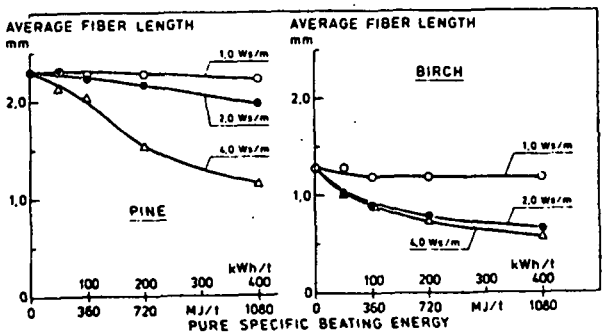
- POTENTIAL PULP PROPERTY DEVELOPMENT

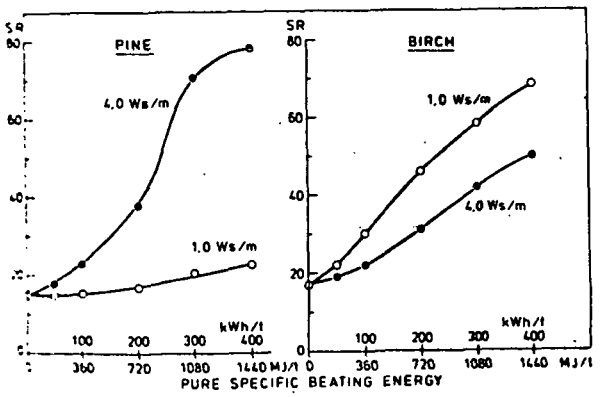
SO WHAT?

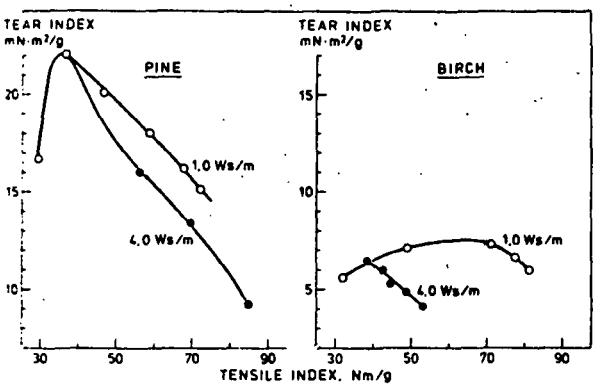
- POTENTIAL PULP PROPERTY DEVELOPMENT
- WIDE (OR WISE) USE OF LOW-COST FIBER SOURCES

SO WHAT?

- POTENTIAL PULP PROPERTY DEVELOPMENT
- WIDE (OR WISE) USE OF LOW-COST FIBER SOURCES
- MATCHING REFINING PARAMETERS WITH PAPERMAKING AND END-USE REQUIREMENTS

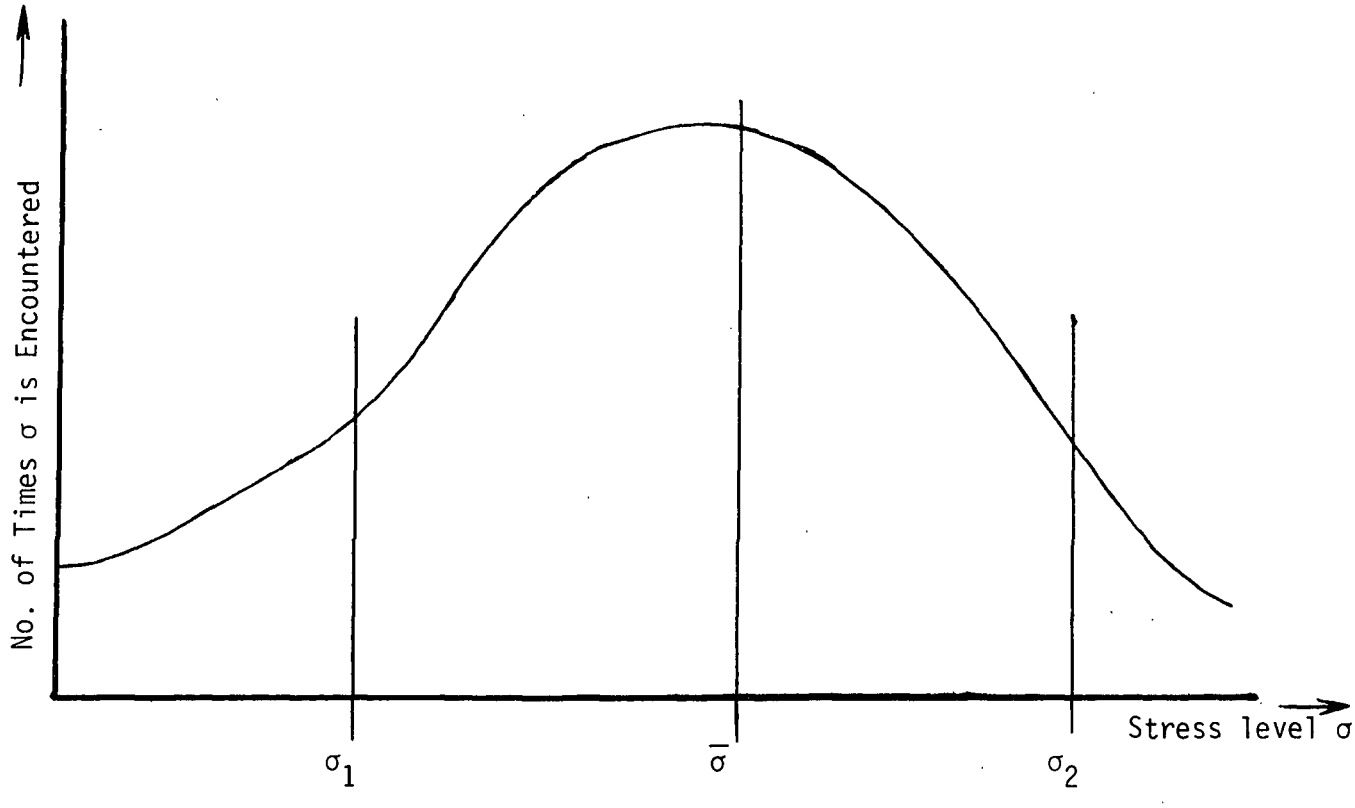






Properties of bleached pine and birch kraft pulps at various levels of specific edge load.

DISTRIBUTION OF STRESS LEVELS
EXPERIENCED BY A SINGLE FIBER



WHICH FIBER STRESSES PRODUCE WHICH NEGATIVE REFINING EFFECTS?

- NORMAL COMPRESSIVE STRESS
- FIBER TENSILE STRESS
- FIBER SHEAR STRESS

NORMAL COMPRESSIVE STRESS

$$\overline{P}_n = \frac{2P}{\mu\Omega Z^2 L \overline{\ell}(D-1/2\cos\theta)}$$

FIBER SHEAR STRESS

$$\overline{\tau}_f = \frac{2(\mu_f/\mu)P}{\Omega Z^2 L \overline{\ell}(D-1/2\cos\theta)}$$

FIBER TENSILE STRESS

$$\bar{\sigma}_f = \frac{2(\mu_f/\mu)P\ell}{\Omega Z^2 L\bar{\ell}(D-1/2\cos\theta)t_f}$$

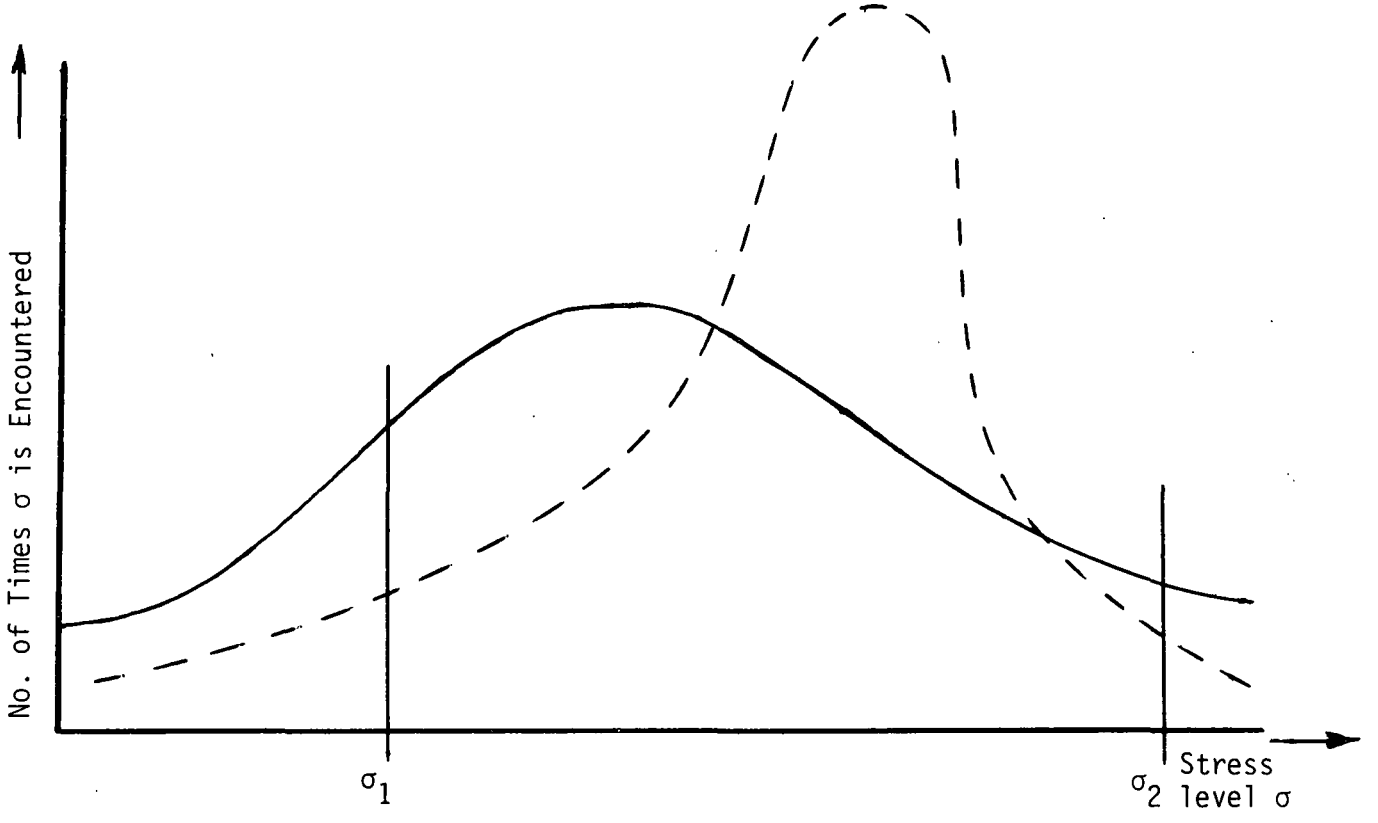
EXPERIMENTAL APPROACHES

- IN-REFINER MEASUREMENT OF P_N
- VERIFICATION OF $\bar{\tau}_f$ AND $\bar{\sigma}_f$ EXPRESSIONS

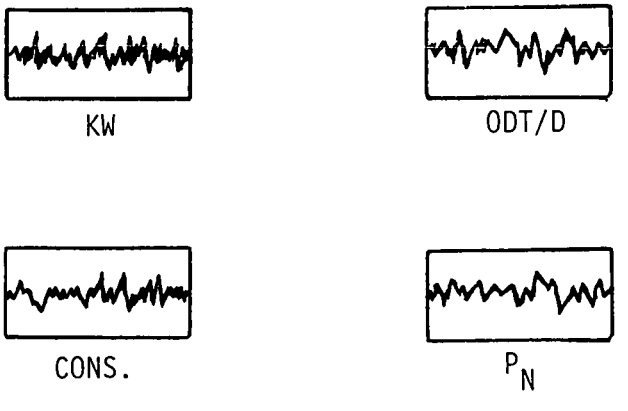
SUMMARY

- PROBLEM
- APPROACH TO SOLUTION
- POTENTIAL ULTIMATE BENEFIT

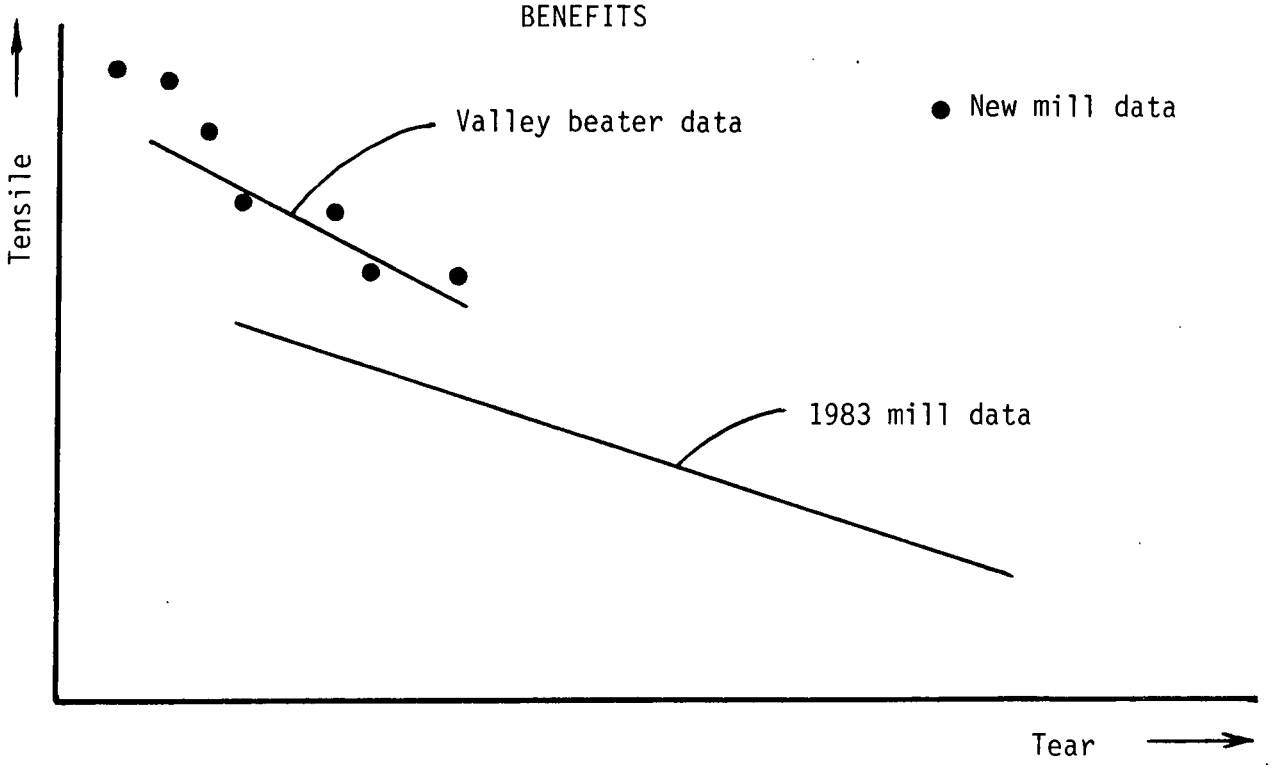
STRESS LEVEL DISTRIBUTIONS



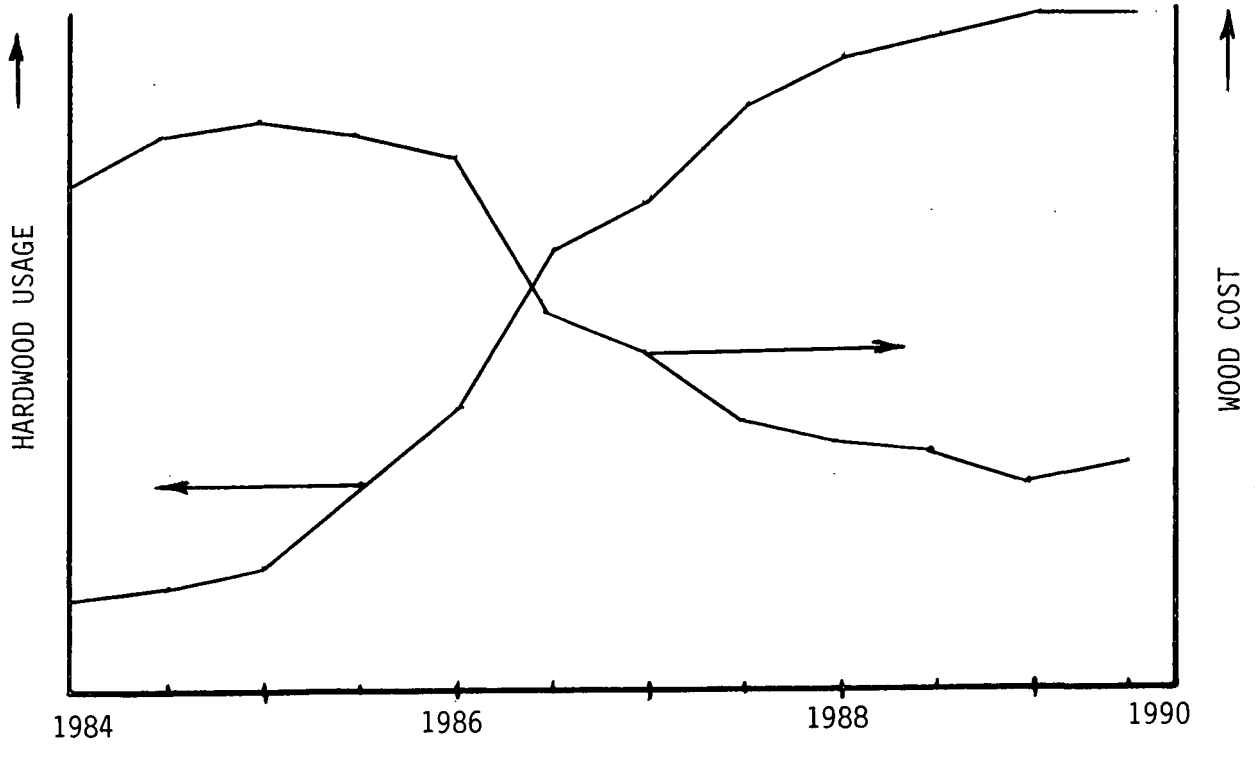
REFINER CONTROL STATION



BENEFITS



BENEFITS



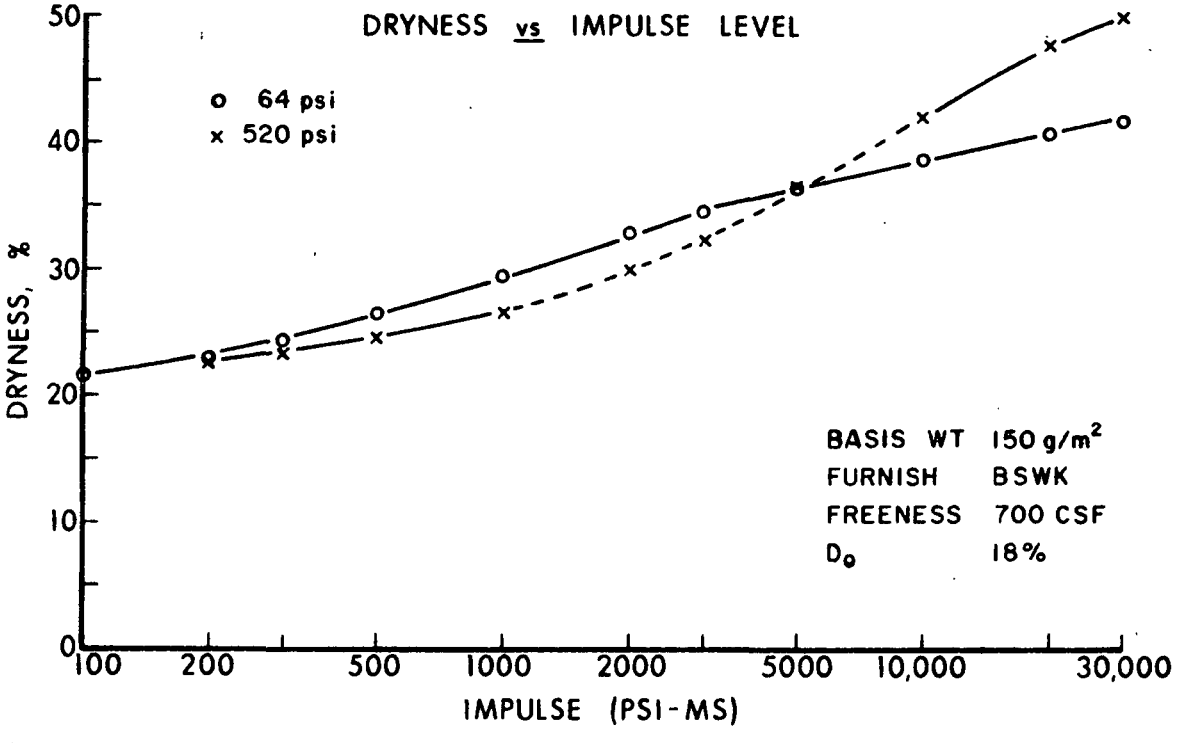
Project 3480

WET PRESSING FUNDAMENTALS

Clyde H. Sprague

PROJECT 3480

FUNDAMENTALS OF WET PRESSING



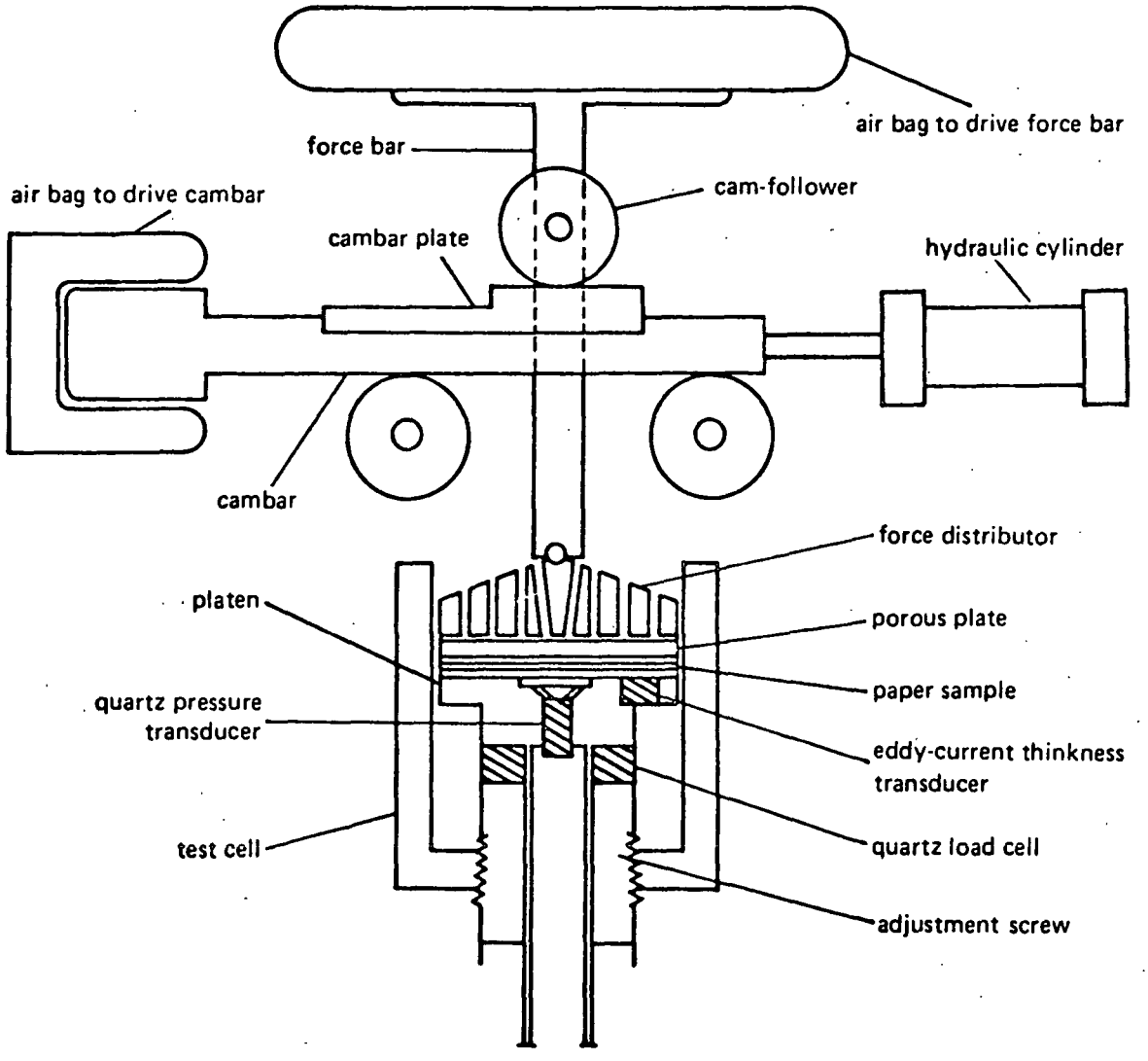
Outgoing dryness as a function of press impulse and pressure.

OBJECTIVE 1: SUBSTANTIALLY IMPROVE EFFECTIVENESS OF FLOW CONTROLLED PRESSING

ADVANTAGES: FEWER PRESSES

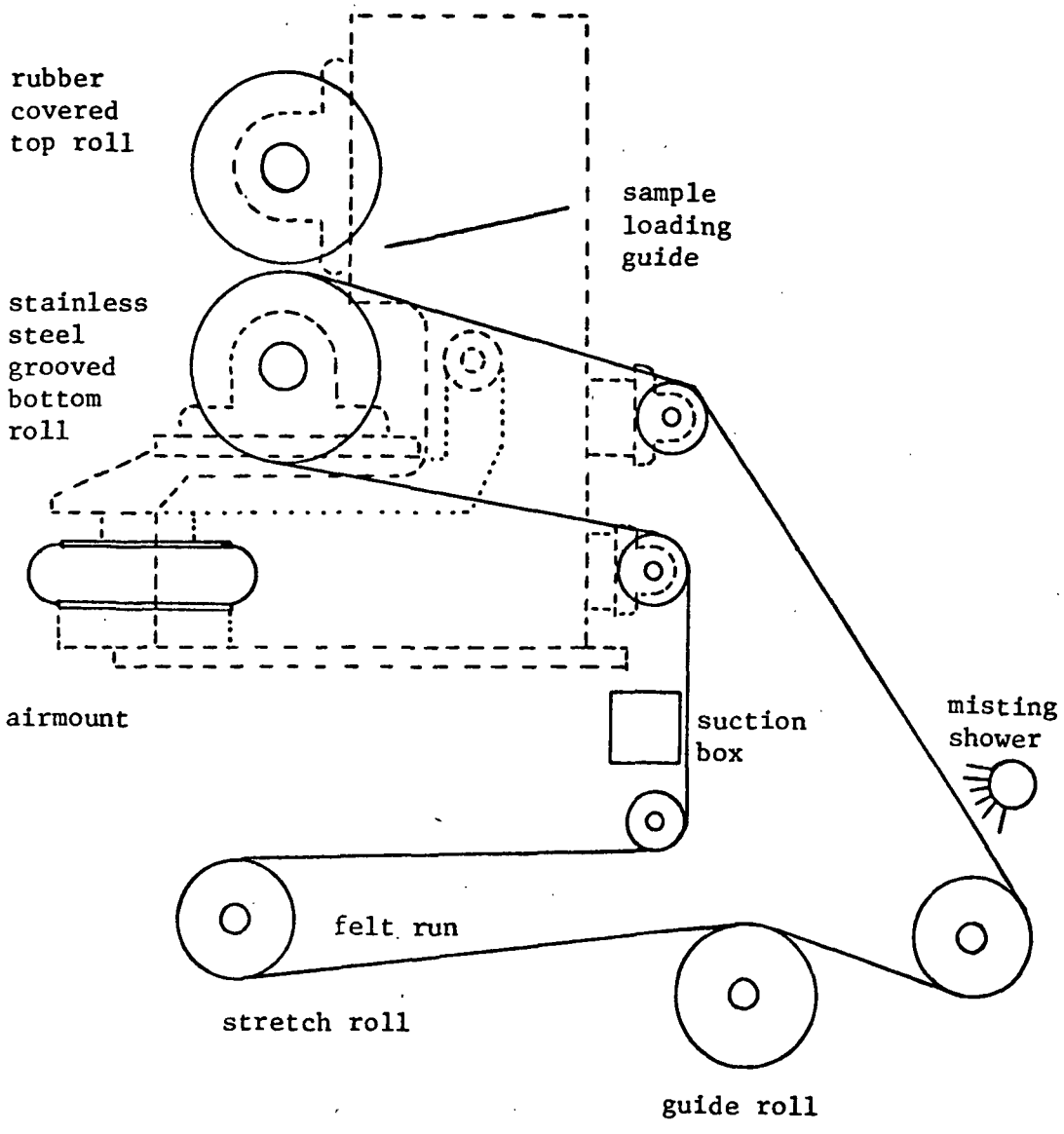
HIGHER DRYNESS

GREATER PRODUCTIVITY

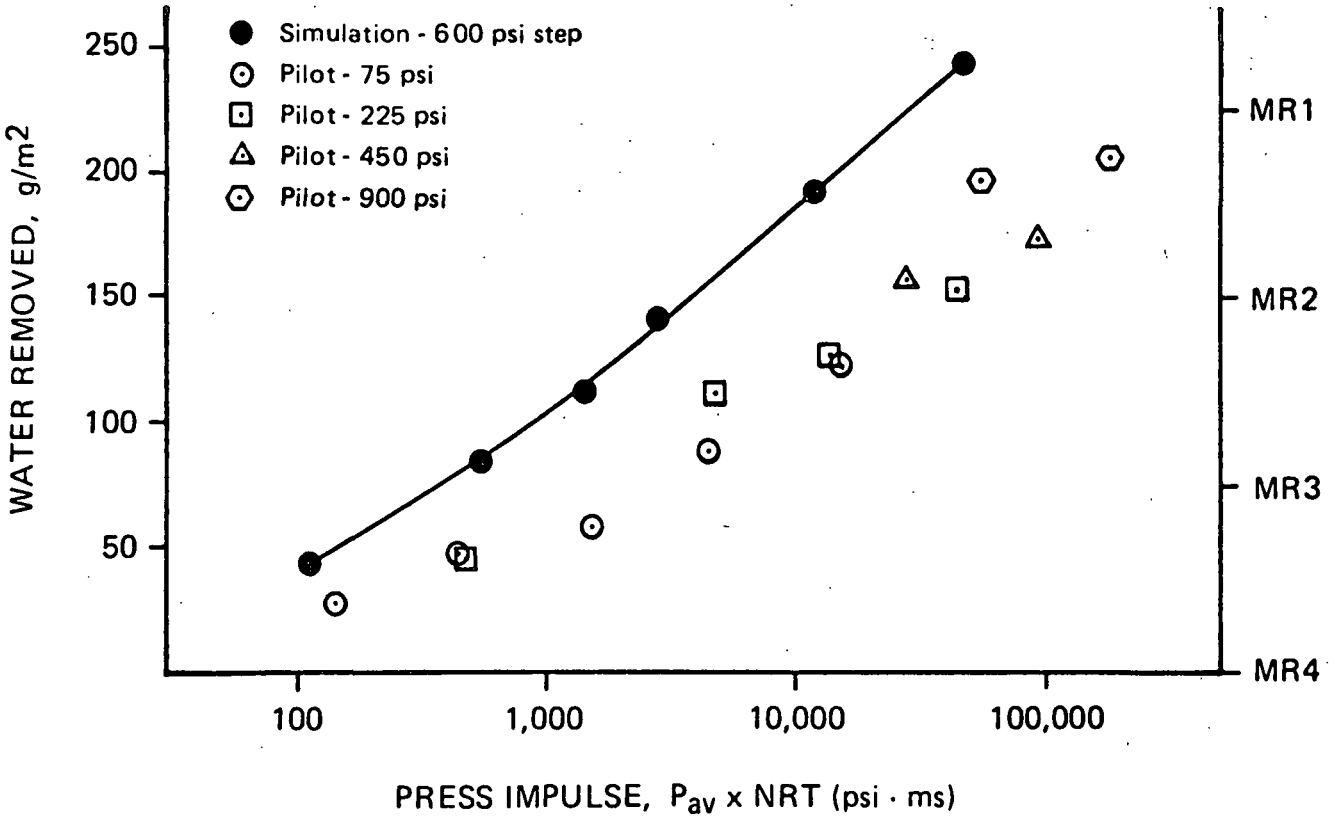


SCHEMATIC DRAWING OF UMO COMPRESSION TESTER

PILOT PRESS



Broken or dotted lines indicate parts of frame or bearings



Comparison between pilot and laboratory simulations for 300 CSF bleached softwood kraft, 75 g/m^2

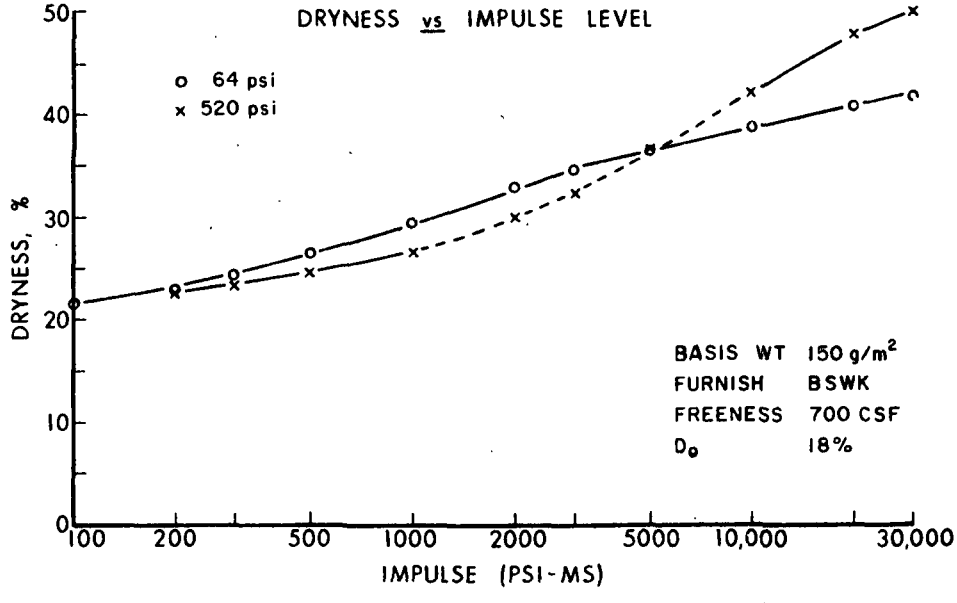
WILL A NEW WATER RECEIVER SYSTEM SUBSTANTIALLY IMPROVE PRESS EFFECTIVENESS?

RESEARCH PLAN

- COMPARATIVE TESTS ON PRESS SIMULATOR
- IDENTIFY CHARACTERISTICS REQUIRED OF WATER RECEIVER
- DETERMINE ECONOMIC FEASIBILITY
- LABORATORY BENCH/PILOT DEMONSTRATION

STATUS

- POROUS MATERIALS AND FELTS ON HAND
- TEST PROCEDURES BEING WORKED OUT
- TEST PLAN UNDER DEVELOPMENT
- VALID COMPARATIVE TESTS TO BEGIN SHORTLY



Outgoing dryness as a function of press impulse and pressure.

OBJECTIVE 2: EVALUATE/DEVELOP THE DISPLACEMENT CONCEPT FOR PRESSING TO MUCH HIGHER DRYNESS LEVELS

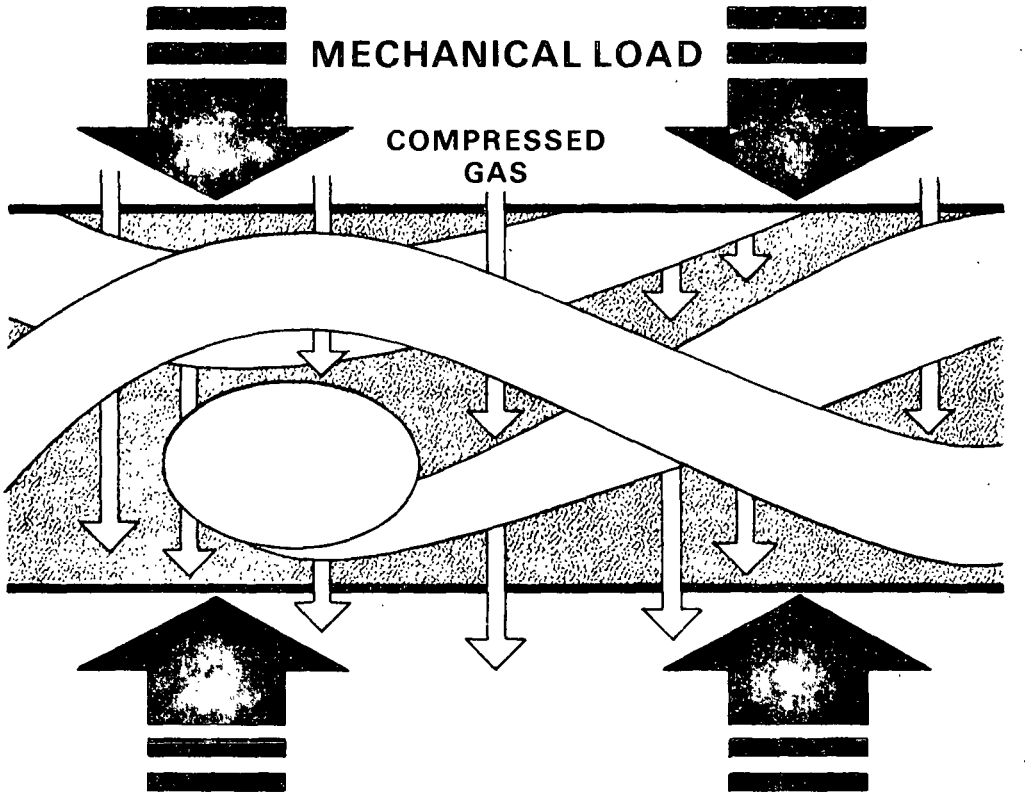
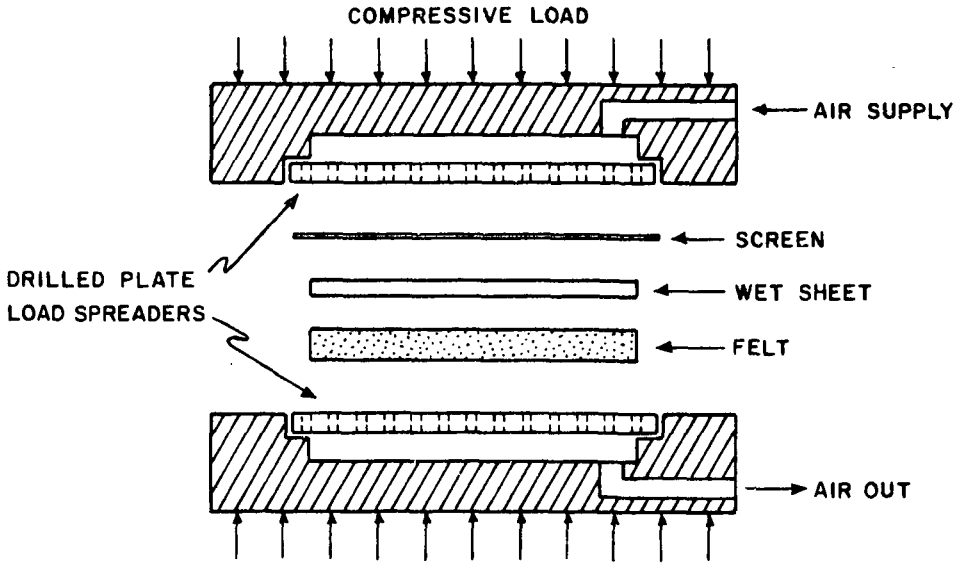


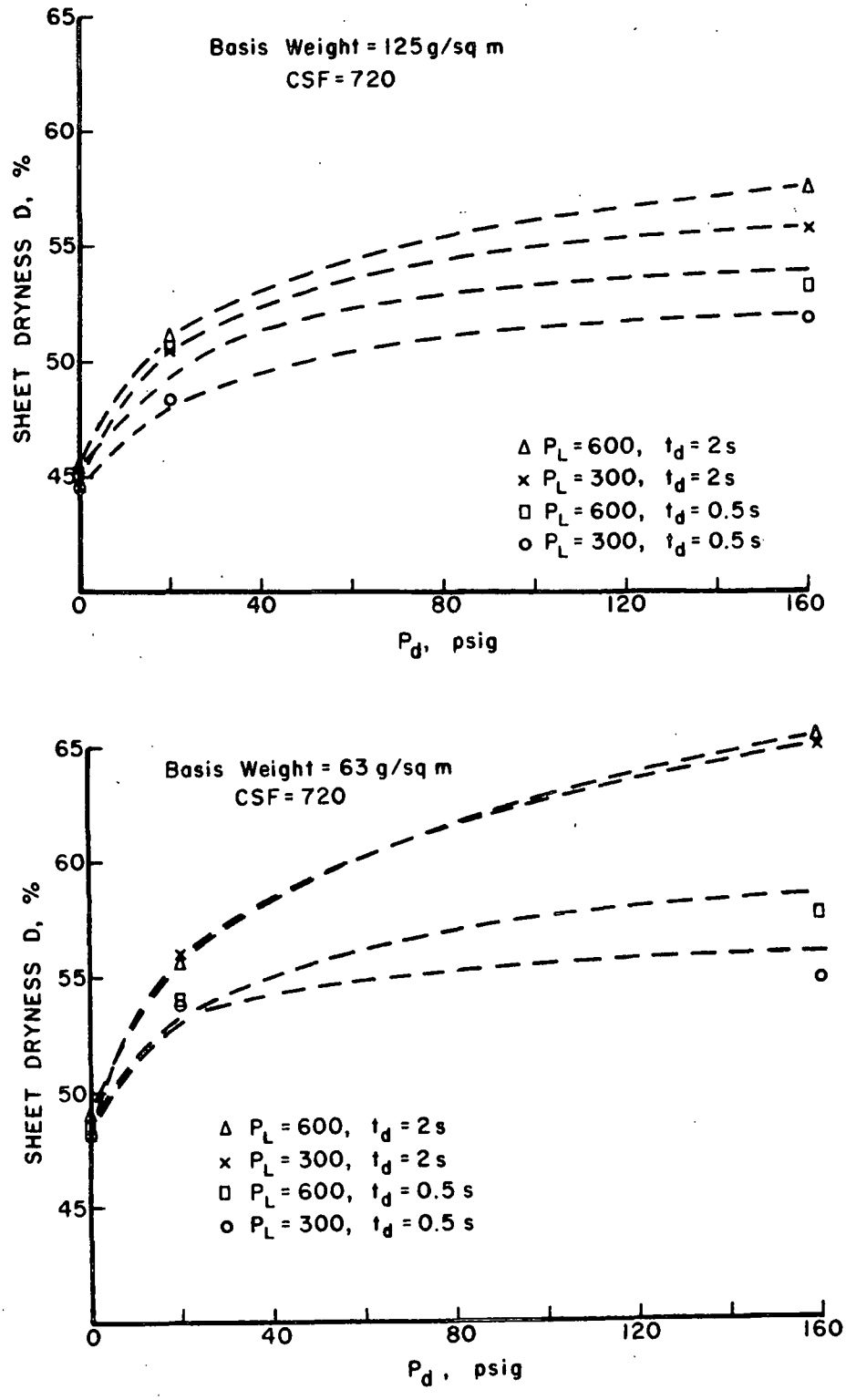
Illustration of displacement pressing concept.



Exploded view of displacement press unit.

IMPORTANT DISPLACEMENT PRESSING VARIABLES

- P_L pressing pressure
- P_d displacement or air pressure
- t_d displacement time
- BW sheet basis weight
- CSF freeness
- D_o initial sheet dryness
- D_f final sheet dryness



Sheet dryness resulting from displacement pressing at various displacement pressures0

ADVANTAGES OF DISPLACEMENT PRESSING

- SMALLER DRYER OR PRODUCTION INCREASE
- LESS DRYING ENERGY/TON
- PROPERTY CONTROL
- IMPROVED WET WEB STRENGTH/RUNNABILITY

LIMITATIONS OF APPARATUS

- POOR EDGE-SEALING
- SEVERE PRESSURE NONUNIFORMITY
- FLOW CAPACITY/PRESSURE BUILDUP
- FLOW RESISTANCE
- STATIC COMPRESSION
- REWETTING - LONG CONTACT TIME

RESEARCH PLAN - DISPLACEMENT PRESSING

- TECHNICAL FEASIBILITY
- EVALUATE ECONOMIC AND ENGINEERING FEASIBILITY
- PERFORMANCE AND ENGINEERING DATA
- LABORATORY DEMONSTRATION

GRADE/FURNISH MATRIX

	News	Writing	Tissue	Liner	Medium	Boxboard
FURNISH	TMP	BSWK	BSWK	USWK	NSSC	Recycled
BW	30	50	7.5	42	26	?
CSF	350	300	400	600	?	?

PROPERTIES MATRIX

News	Writing	Tissue
Tear	Tear	Water absorption
Ink penetration	Ink penetration	Stiffness
Brightness	Brightness	Wet strength
Opacity	Opacity	Porosity
Smoothness	Smoothness	Brightness
Porosity	Porosity	Light scattering
Pick	Pick	Bulk
	Water resistance	
	Folding endurance	

PROPERTIES MATRIX (CONTD.)

Liner	Medium	Boxboard
Burst	Concora	Stiffness
STFI	STFI	STFI
Smoothness	Water drop	Plybond
		Smoothness
		Ink absorption
		Pick

Project 3470

FUNDAMENTALS OF DRYING

Fred W. Ahrens

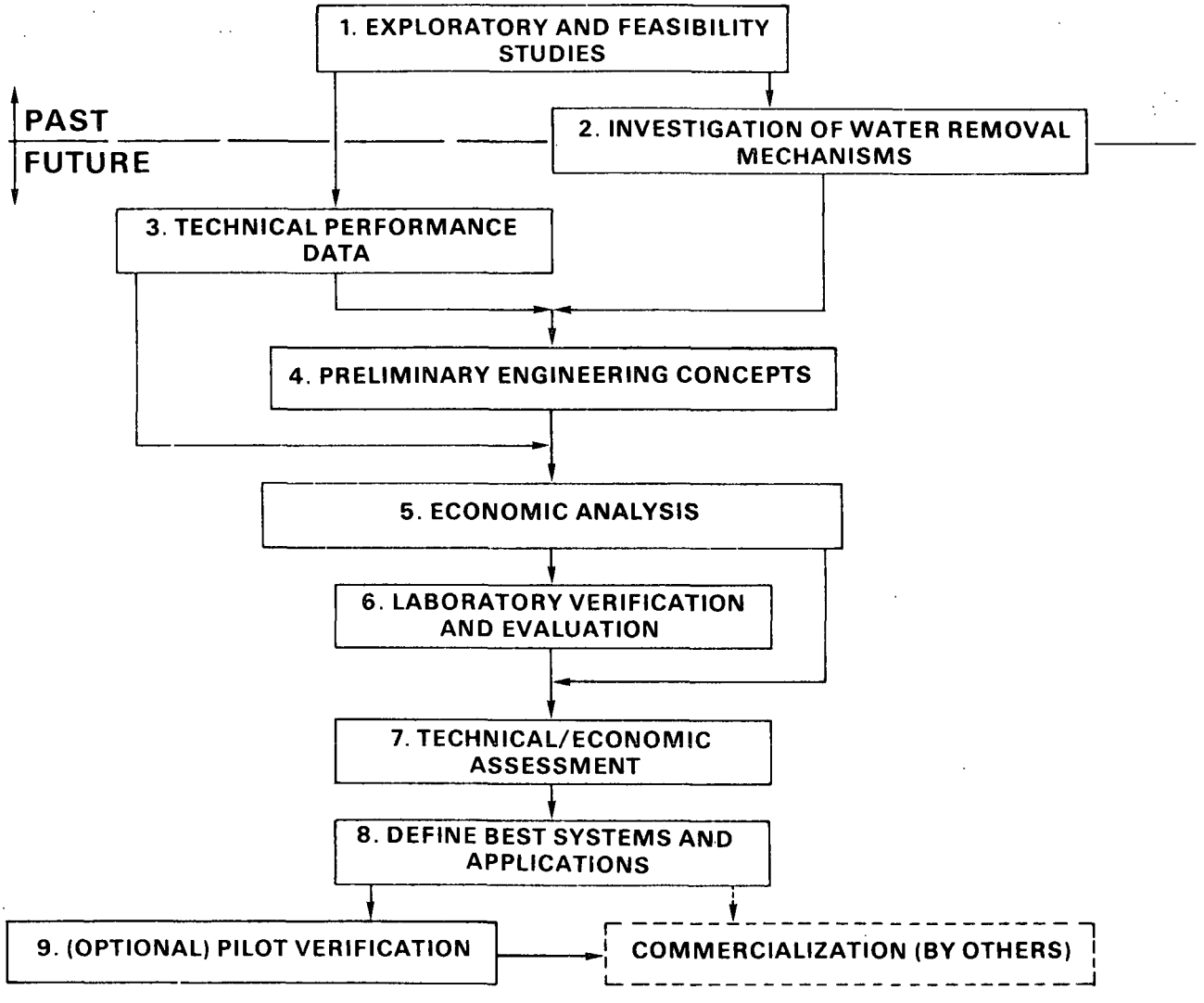
FUNDAMENTALS OF DRYING

PROJECT 3470

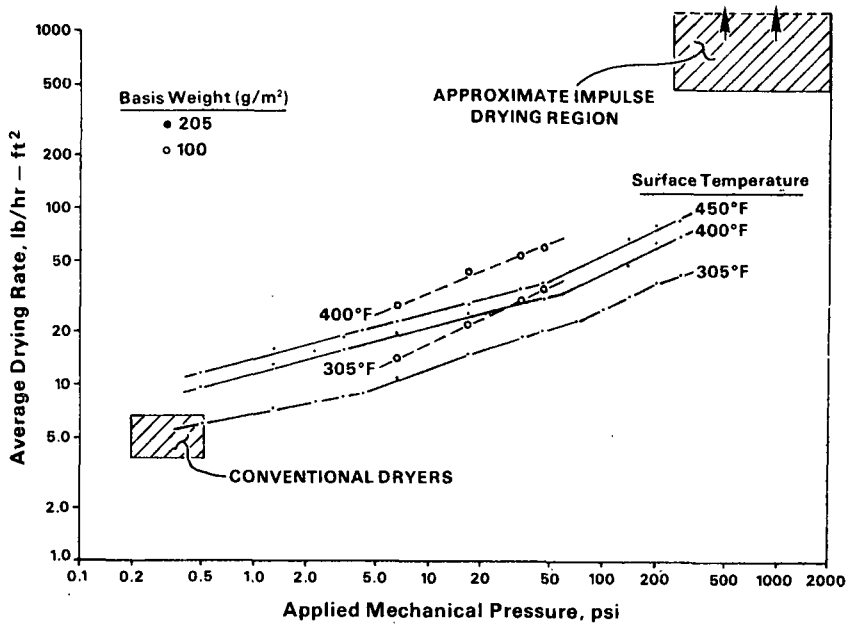
PROJECT OBJECTIVE

Develop understanding and data base relative to high-potential drying processes.

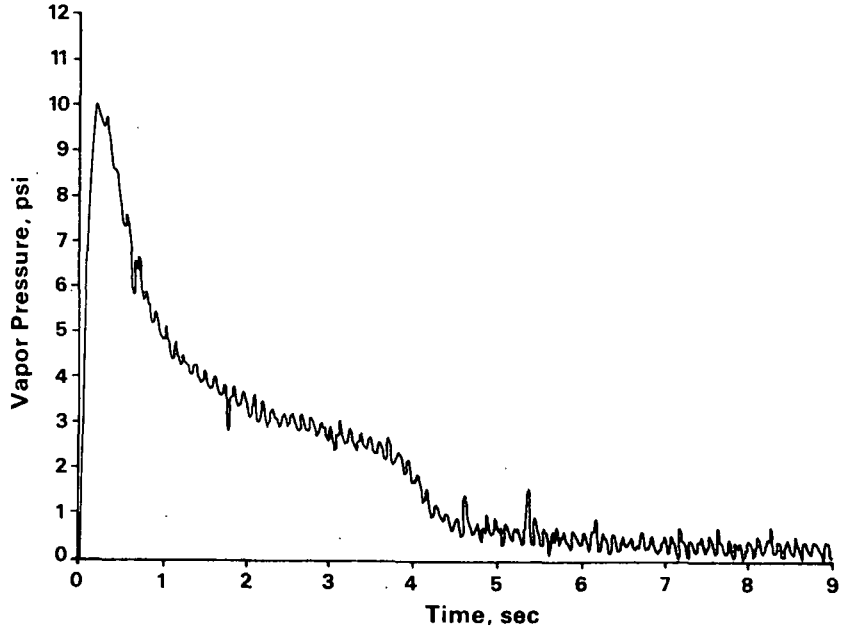
Goal: Enable commercialization of significantly improved water removal systems to proceed.



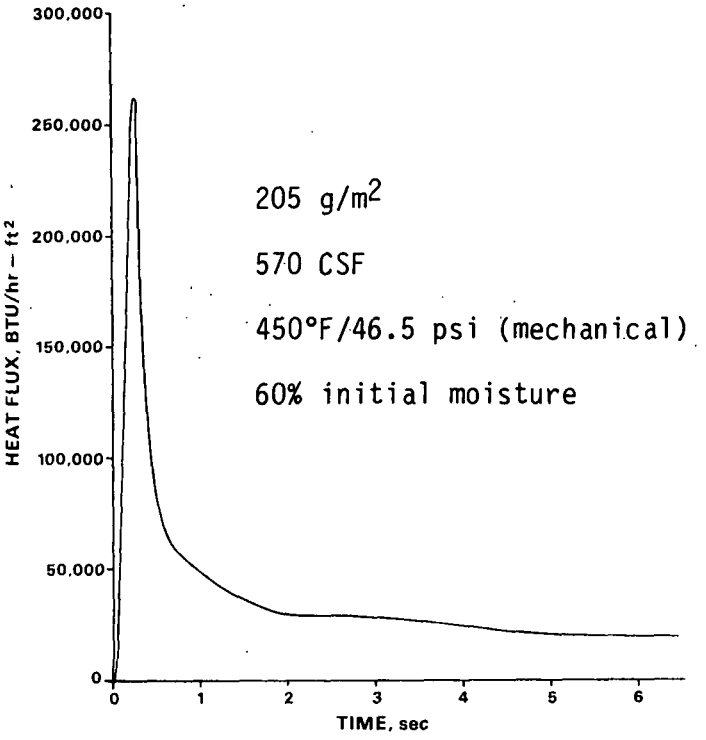
Long range project elements.



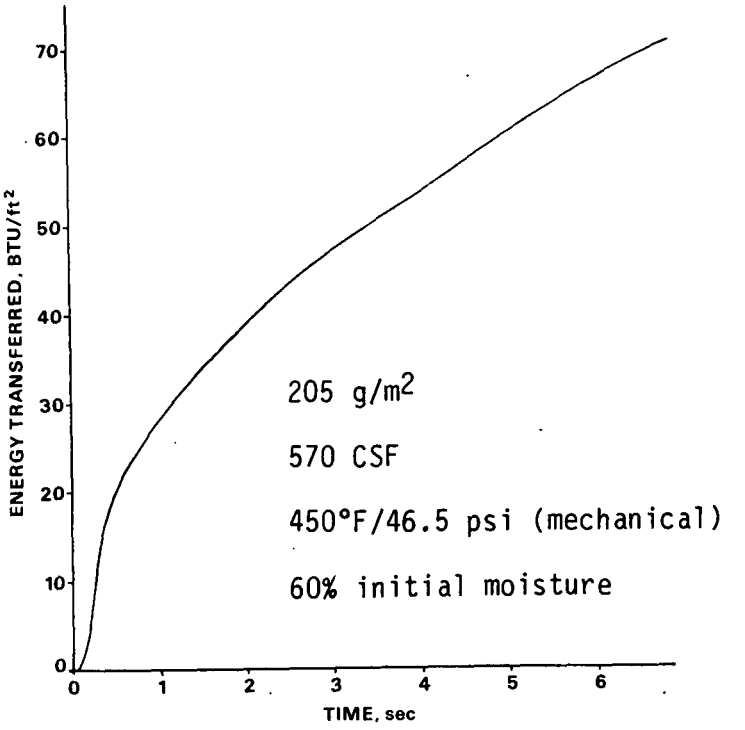
Average drying rate for unbleached softwood kraft handsheets with 60% initial moisture content, 6% final moisture content.



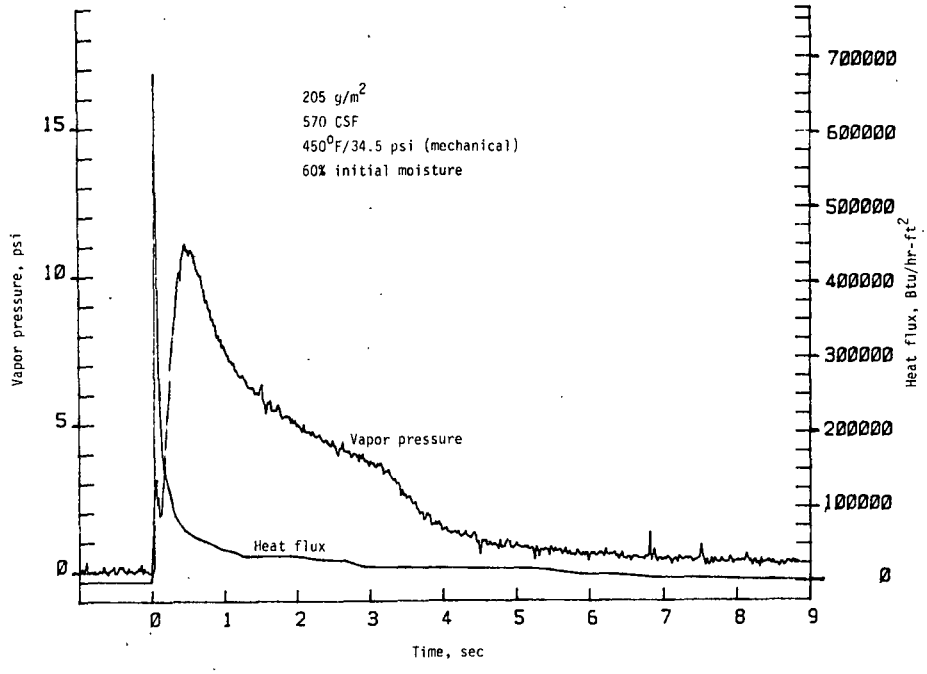
Vapor pressure at hot surface for unbleached softwood kraft handsheet, 205 g/m^2 basis weight, 60% initial moisture, 570 CSF, at 450°F surface temperature, 46.5 psi mechanical pressure.



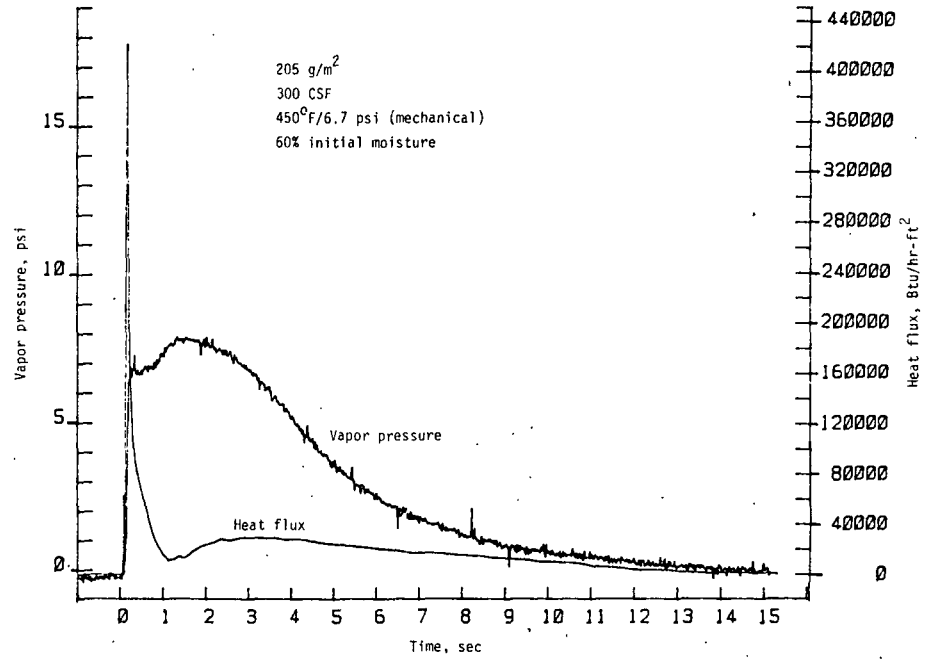
Heat flux into sheet.



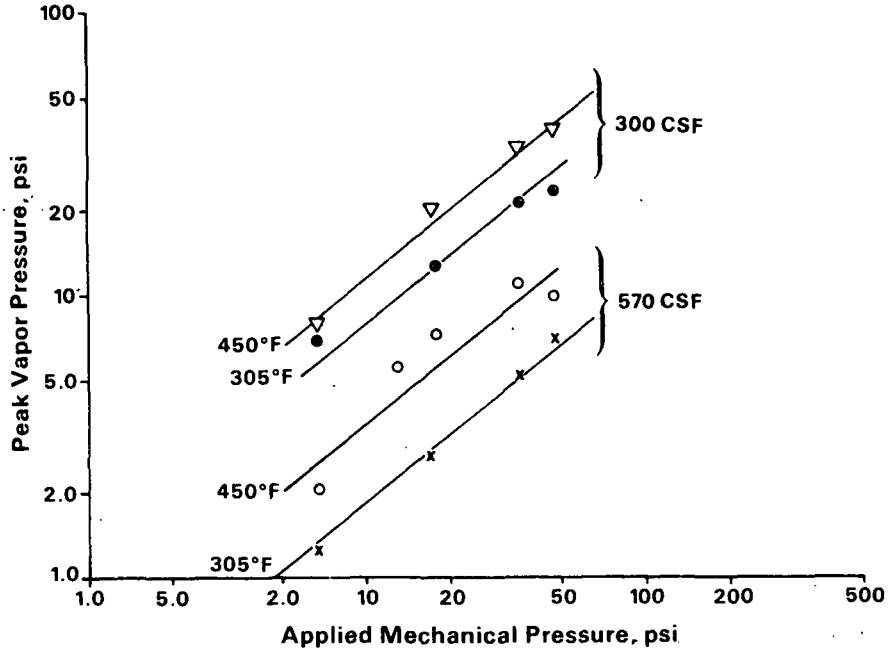
Energy transferred to sheet.



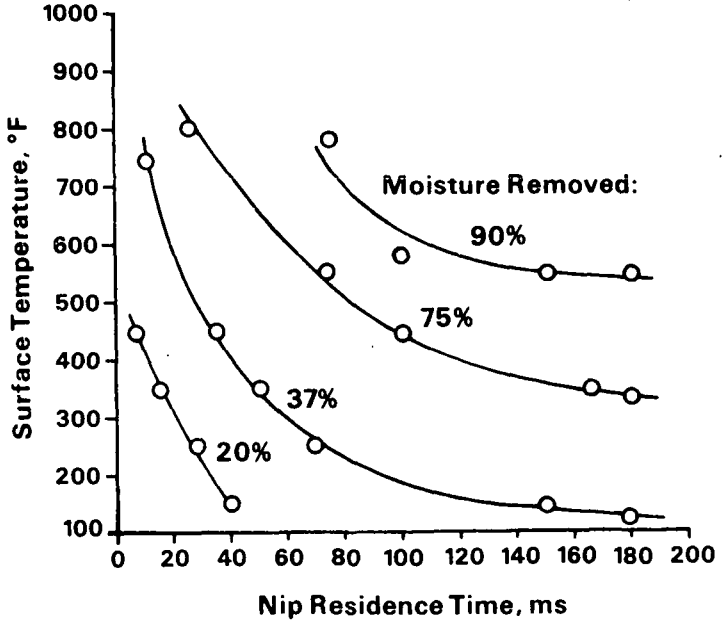
Heat flux and vapor pressure at hot surface.



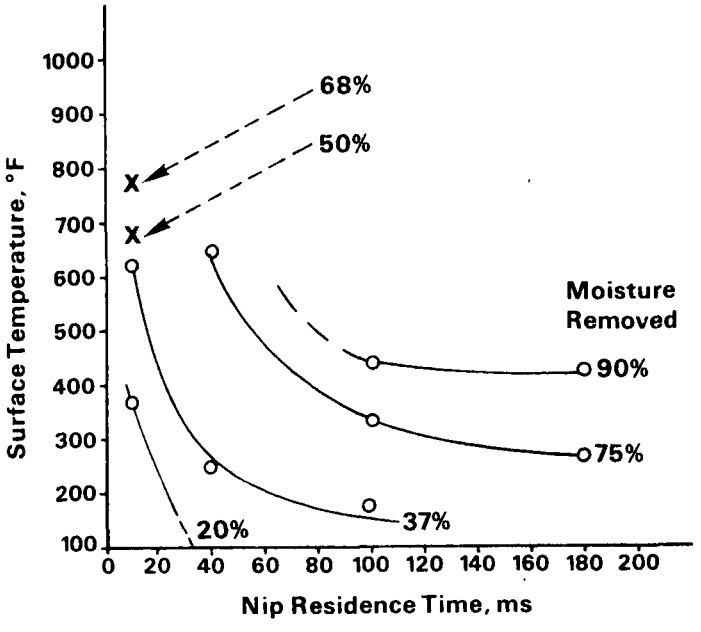
Evidence of "liftoff" at high temperature/ low mechanical pressure.



Peak vapor pressure at hot surface for unbleached softwood kraft handsheets, 205 g/m^2, 60% initial moisture content.



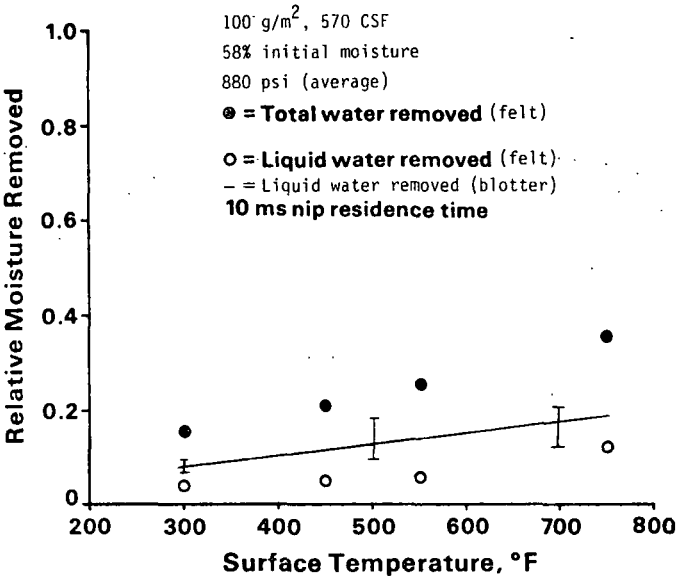
Relative moisture removed during impulse drying: 100 g/m^2 unbleached softwood kraft handsheets (570 CSF) at 58% initial moisture content, with 880 psi average mechanical pressure applied.



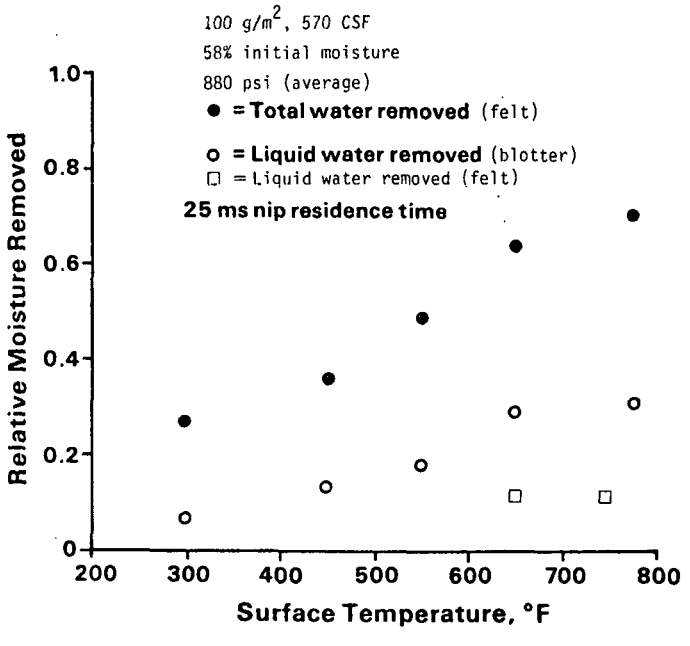
Relative moisture removed during impulse drying: 100 g/m^2 unbleached softwood kraft handsheets (570 CSF) at 58% initial moisture content, with 1760 psi average mechanical pressure applied.

HEAT INPUT OPTIONS

1. Direct heating of shell:
   - Combustion gases
   - Electrical
2. Indirect heating:
   - Heated liquids
   - IR (gas or electrical)



Total relative moisture removed and relative moisture removed as liquid.



Total relative moisture removed and relative moisture removed as liquid.

GRADE/FURNISH MATRIX

	News	Writing	Tissue	Liner	Medium	Boxboard
FURNISH	TMP	BSWK	BSWK	USWK	NSSC	Recycled
BW	30	50	7.5	42	26	?
CSF	350	300	400	600	?	?

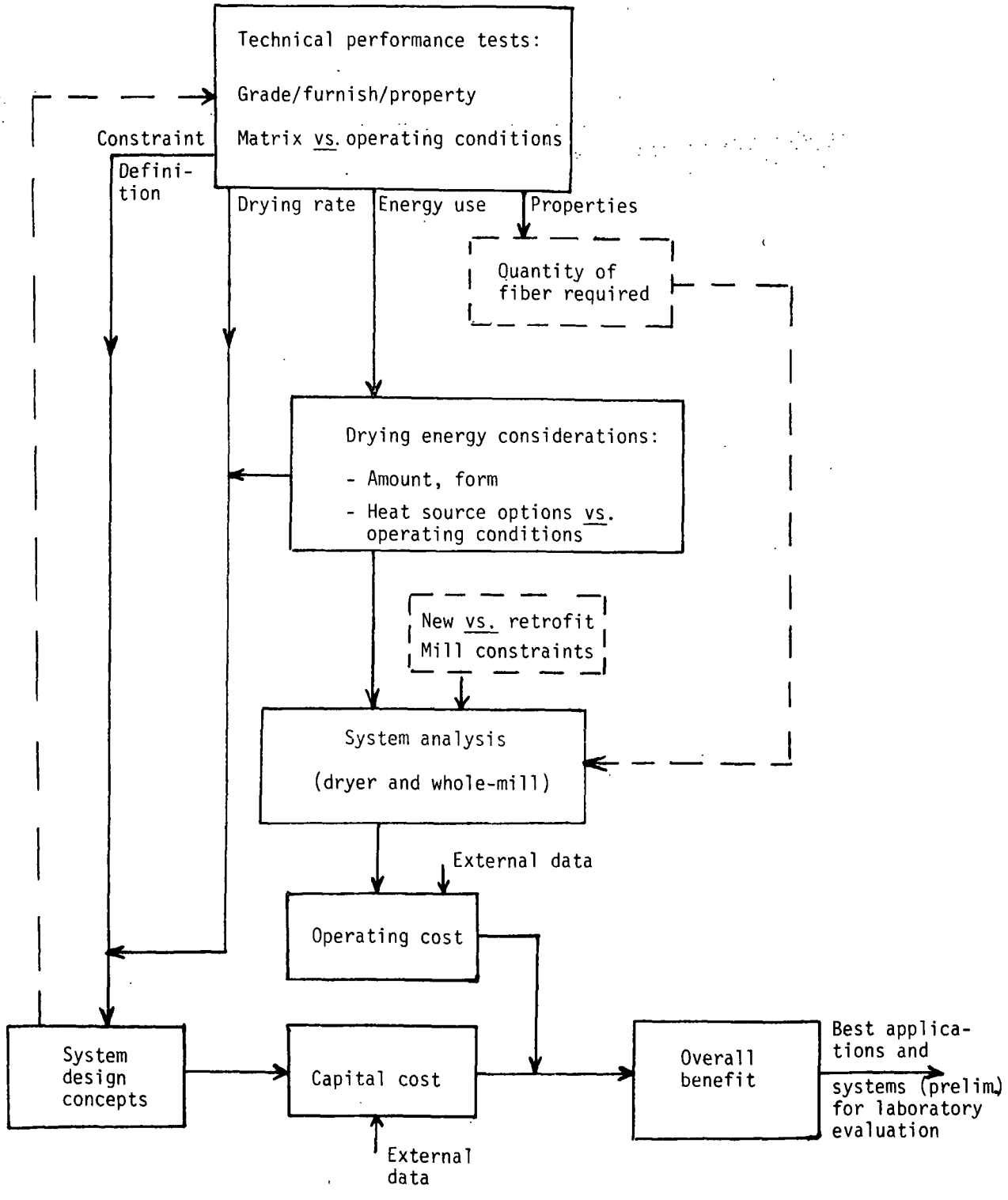
PROPERTIES MATRIX

News	Writing	Tissue
Tear	Tear	Water absorption
Ink penetration	Ink penetration	Stiffness
Brightness	Brightness	Wet strength
Opacity	Opacity	Porosity
Smoothness	Smoothness	Brightness
Porosity	Porosity	Light scattering
Pick	Pick	Bulk
	Water resistance	
	Folding endurance	

PROPERTIES MATRIX (CONTD.)

Liner	Medium	Boxboard
Burst	Concora	Stiffness
STFI	STFI	STFI
Smoothness	Water drop	Plybond
		Smoothness
		Ink absorption
		Pick

PRELIMINARY IDENTIFICATION OF
BEST APPLICATIONS AND SYSTEMS



NEAR TERM GOALS

1. Prepare versatile drying system

2. Initiate broad characterization test program:

   - Finalize grade/furnish/property test matrix
   - Baseline tests (properties)
   - Systematic evaluations of drying performance and paper properties

3. Engineering and system aspects for each grade:

   - Define drying system configurations and heat source alternatives
   - Engineering and system (mill-wide) analyses of alternatives

Project 3479

HIGHER-CONSISTENCY PROCESSING

John D. Sinkey

HIGHER CONSISTENCY PROCESSING

PROGRAM GOAL:

Reduction of the complexity of screening, cleaning, and forming systems.

PROJECT OBJECTIVE

To identify or develop methods and principles for controlling fiber motion in HC slurries, as applied to practical forming and separation processes.

HC PROBLEMS

- Fiber network dispersion
- Fiber orientation

SHORT-TERM TASKS

1. Identification and categorizing
2. Assessment
3. Prioritizing
4. Preliminary experiments
5. Reassessment
6. In-depth studies

CATEGORIES OF HC SEPARATION CONCEPTS

- Shear in liquid phase
- Sprayed particles
- Abrupt turns into holes
- Intense turbulence in conventional equipment

CATEGORIES OF HC FORMING CONCEPTS

- Elongational flow - extrusion
- Forming fabric in turbulent zone
- Elongational flow - vena contracta
- Carding or combing
- Drafting or wet straining
- Multilayer HC headbox
- Sequential deposition by spray
- Ultra-short circulation

CRITERIA FOR ASSESSMENT -

WHICH CONCEPT SHOULD
WE WORK ON FIRST?

- Odds for favorable result

CRITERIA FOR ASSESSMENT -

WHICH CONCEPT SHOULD
WE WORK ON FIRST?

- Odds for favorable result
- Potential benefit

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- Complexity of preliminary study

CRITERIA FOR ASSESSMENT -

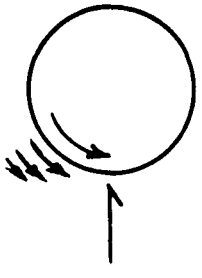
WHICH CONCEPT SHOULD
WE WORK ON FIRST?

- Odds for favorable result
- Potential benefit
- Complexity of preliminary study
- Appropriateness for IPC

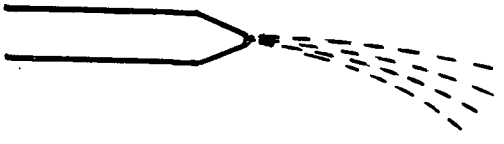
ASSESSMENT OF TOP THREE HC CONCEPTS

Concept or Approach	Odds for Success, %	Potential Benefit	Facility and Cheapness of Prelim. Study	Aptness for IPC	Overall Rating, %
Separation by shear in liquid phase	25	9	6	9	66
Separation of sprayed particles	30	8	6	7	60
Elongational flow-extrusion forming	10	8	6	7	55

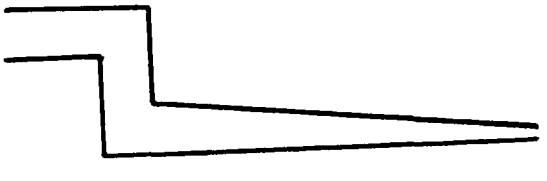
SEPARATION BY SHEAR IN LIQUID PHASE



SEPARATION OF SPRAYED PARTICLES



ELONGATIONAL FLOW - EXTRUSION FORMING



FUTURE WORK

- Task 4. Preliminary studies
- Task 5. Reassessment
- Task 6. In-depth study

BENEFITS OF HC FORMING

- High speed tissue machine
- Fourdrinier

BENEFITS OF HC SCREENING/CLEANING

- Size of systems, components
- Operating costs
- Elimination of dilution steps
- Elimination of thickening